Monthly Variability in the Ocean Habitat off Peru as Deduced from Maritime Observations, 1953 to 1984

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Abstract

Monthly time series, generated from summaries of maritime reports from the region off Peru, are presented for the period 1953 to 1984. These include sea surface temperature, cloud cover, atmospheric pressure, "wind-cubed" index of rate of addition of turbulent mixing energy to the ocean by the wind, wind stress components, solar radiation, long-wave back radiation, evaporative heat loss and net atmosphere-ocean heat exchange. All series are found to undergo interrelated nonseasonal variations at multiyear periods. El Niño episodes are characterized by intense turbulent mixing of the ocean by the wind, intense offshore-directed Ekman transport and by low net heat gain to the ocean through the sea surface. Effects of constant versus variable transfer coefficient formulations on the bulk aerodynamic flux estimates are discussed. Certain comments on the utilization of these data in analysis of biological effects are offered.

Introduction

By international convention, weather observations are recorded routinely on a various types of ships operating at sea. These maritime reports remain the primary source of information on large-scale variability in the marine environment. Even with the increasing development of satellite observation systems, analysis of time series of decadal length and longer must continue to depend heavily on these maritime reports for some time to come. Observations of wind speed and direction, air and sea temperature, atmospheric pressure, humidity and cloud cover included in these reports provide a basis for estimating a number of environmental variables pertinent to the study of variations in ocean climate and of effects of these variations on the associated communities of marine organisms. In this paper, the historical files of these observations are summarized to yield monthly estimates of properties and processes at the sea surface within the extremely productive upwelling ecosystem off central and northern Peru. The 32-year period treated encompasses several dramatic El Niño events and the spectacular rise, collapse, and indications of a recent rebound, of the largest exploited fish population that has ever existed, the Peruvian anchoveta.

Although remarkably rich both in biological productivity and in climatic scale ocean variability, the area off Peru is rather poor in maritime data density. Thus the region presents a particular challenge to the methodologies employed here. The area is very sparsely sampled in comparison to the corresponding eastern ocean boundary ecosystems of the northern hemisphere, with most of the reports coming from a narrow coastal shipping lane lying within about 200 km of the coast (Parrish et al. 1983). Maritime reports are subject to a variety of measurement and transmission errors, of which improper positioning is perhaps the most troublesome, sometimes introducing very large errors in all derived quantities (e.g., when a wrong hemisphere, etc., may be indicated). And it is difficult to establish effective procedures for rejecting erroneous reports without also suppressing indications of real variations, particularly in the area off Peru which is perhaps uniquely subject to drastic and abrupt natural environmental perturbations. For example, early indications of the 1982-1983 El Niño event went unnoticed by meteorological agencies in Europe and North America, because the reports which clearly indicated an event of unprecedented intensity were so far from the norm that they are rejected as erroneous by the automated data editing procedures (Siegel 1983). In addition, even when no actual errors are involved, irregular distribution of the reports in both time and space may introduce biases and nonhomogeneities into time series constructed from these data.

Tests of the precision of the methodology on interyear time scales, involving subsamplings of the much richer data distributions off the Iberian Peninsula in the northeast Atlantic Ocean, have indicated benefits to be gained by utilizing rather large areal samples, i.e., of the order of 10 degrees of latitude and longitude in extent, with the increase in report frequency overriding increases in sampling variance resulting from incorporation of additional spatial variability (Bakun, unpublished data). These same tests have indicated that the use of the ordinary 'standard error of the mean' provides a useful guide to the precision of monthly estimates, even though the underlying processes may be very highly variable on much smaller temporal and spatial scales than those used for data summarization. For the time series presented herein, reports available within an area extending some 10 degrees of latitude along the Peru coast and about 4 degrees of longitude offshore (Fig. 1), between Talara and a point just to the south of Pisco, were

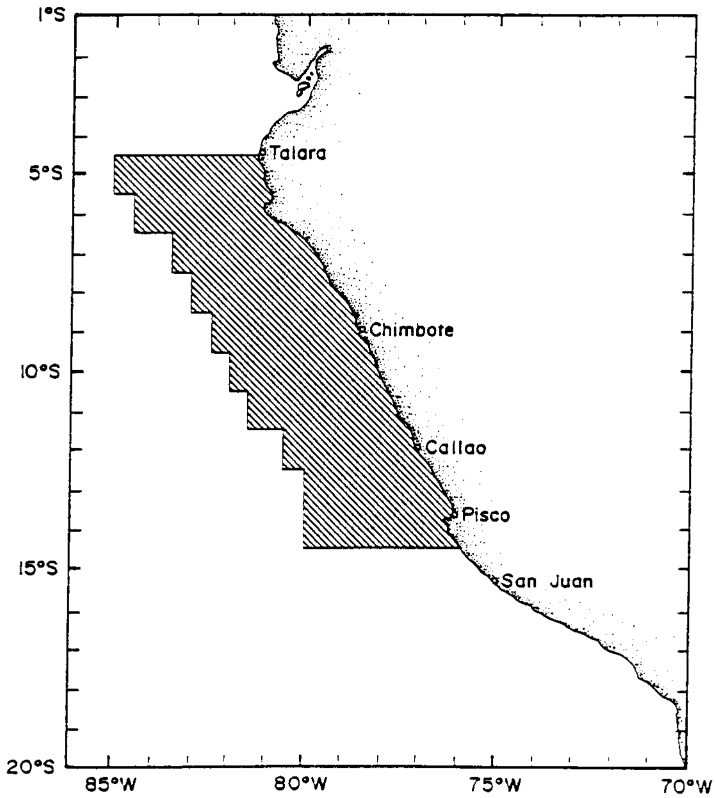

Fig. 1. Summary area. Maritime reports from within the area indicated by diagonal hatching were used for assembling monthly samples.

composited together. These composite samples are assumed to characterize temporal variability, at least in the relative sense, in conditions affecting the neritic fish habitat along that stretch of coastline which appears to have some degree of natural unity both in terms of environmental processes and biological community (Santander 1980; Parrish et al. 1983). The rather ragged offshore edge of the summary region was chosen to facilitate initial extraction of the reports from the data archive files. Consistent features of spatial variability tend to be much less intense in offshore areas of coastal upwelling regions than in coastal areas; thus no substantial effect of the irregularity of shape of the offshore boundary is expected. Also all the monthly summaries are treated identically in terms of areal selection and so time series homogeneity is preserved. In any case, report density is extremely low at the outer edge of the summary area.

Assembly of Data Series

Impossible or highly improbable values occur occasionally in the maritime report files, due to keypunch errors, etc. In the data record format, temperature values between -99.9 and 99.9°C are possible. Initial efforts to construct the data series resulted in rather large standard errors for certain of the monthly values due to incorporation of improbable data. For this reason, only values falling between the limits 11 to 31°C were accepted as valid observations of air temperature, sea surface temperature, or 'wet bulb' air temperature, for this region. (Note that the lower bound on the wet bulb temperature caused only 16 reports, no more than a single report in any one month, to be rejected). Wind speeds of up to 199 knots (102 m/sec) are possible in the record format. Erroneously high wind speeds have a particularly serious effect since wind speed is squared in the stress computation and cubed in the wind mixing index formulation. Reports of wind greater than 45 knots (23 m/sec) occurred within the summary region less than ten times in the entire 32-year record and were in no case corroborated by neighboring (in either space or time) data. Thus wind reports exceeding this value were excluded in preparing these time series. The data record format limited wind direction to values between 0 and 360 degrees, cloud cover observations to the range 0 to 100% of sky obscured, and barometric pressure to values between 890 and 1,070 millibars.

In assembling the monthly data samples, if any one of the reported values of sea surface temperature, barometric pressure, wind speed, or wind direction, were missing or unacceptable the entire report was excluded from the summaries. These four observed properties are sufficient to produce time series of sea surface temperature (Table 2), atmospheric pressure (Table 4), wind stress components (Tables 5 and 6), and wind mixing index (Table 7). The numbers of reports having acceptable observations of these four items are entered as the first of the three numbers shown for each month in Table 1. In addition, if a valid cloud cover observation was available the report was also incorporated in the cloud cover series (Table 3); numbers of reports including acceptable observations of these five items are entered as the second number of each monthly set in Table 1. Finally, if acceptable values of both air (dry bulb) temperature and either wet bulb or dew point temperature were included, the report was also used for construction of time series of atmosphere-ocean heat exchange components (Tables 8 to 11). Numbers of available reports containing acceptable observations of all seven properties required to construct all the time series presented in this paper are shown as the third number under each month in Table 1. All computations of derived quantities were performed on each individual report prior to any summarization process. A simple mean was taken as an estimate of the central tendency of each monthly sample. Computed standard errors of these mean values are displayed within the parentheses following each monthly value presented in the various data tables. An approximate 95% confidence interval estimate can thus be generated by multiplying the indicated standard error by the factor 1.96, and adding and subtracting the result from the monthly mean value (point estimate) to yield the upper and lower limits of the interval.

A small percentage of the reports contain wind observations in which the direction is noted as "variable"; i.e., no direction could be assigned. This properly occurs only when the wind speed is very low. In these cases the wind speed is used, as reported, in the calculations where it enters as a scalar quantity, i.e., in the calculations of wind mixing index, evaporative heat loss and conductive heat loss. In the computation of surface wind stress, wind enters as a vector quantity and directionality is crucial. Accordingly, for the surface wind stress calculations, variable winds are treated as calms. Because the wind speed enters the calculation as a "square", low wind values act essential as zeros in their effect on the monthly means, and so treating these weak variable wind observations as calms has no substantial effect. Also, the net effect of a stress from one direction is cancelled by an equal stress from the opposite direction, and so treating variable-directional stress as equivalent to calm conditions makes physical sense.

Sea Surface Wind Stress

Sea surface stress was estimated according to:

$$(\tau_x, \tau_y) = \rho_a C_D (|\vec{W}_{10}| U_{10}, |\vec{W}_{10}| V_{10}) \qquad \ldots 1)$$

where τ_x and τ_y are components of stress directed onshore and alongshore, respectively; a characteristic onshore direction of 62 degrees and an alongshore direction of 332 degrees (from true north) was assigned to the entire summary area. ρ_a is the density of air, considered constant at 1.22 kg/m^3. C_D is a dimensionless drag coefficient. $|\vec{W}_{10}|$ is the wind speed at 10 m height. U_{10} is the onshore-directed component of wind velocity; V_{10} is the alongshore-directed (positive equatorward) component. For the data series presented in the tables, C_D was considered to be a constant equal to 0.0013. The use of this constant drag coefficient has been a somewhat standard practice in climatological studies of upwelling regions (Bakun et al. 1974; Nelson 1977; Parrish et al. 1983). However, it is recognized that the value of the drag coefficient is actually a variable which depends on the nature of atmospheric turbulence near the sea surface. Thus a dependence on both atmospheric stability and wind magnitude near the sea surface is indicated; the stability effect is particularly important in reducing air-sea transfers in upwelling regions due to the stable atmospheric boundary layer formed over cool upwelled surface water. No clear consensus as to the proper formulation of these dependencies is presently available. However, a reasonable variable drag coefficient formulation has been chosen and has been applied to these data for evaluation of possible differences from results based on the constant drag coefficient formulation. In this case we follow the method of Nelson (1977) for incorporation of the atmospheric stability effect, which is based on a bulk Richardson number parameterization (Deardorff 1968). We incorporate a dependence on wind speed according to the recommendations of Large and Pond (1981) who find a linear increase in the drag coefficient at wind speeds greater than 11 m/sec.

Offshore Ekman Transport

In their climatological study of seasonality and geography of anchovy and sardine reproductive habitats within eastern ocean boundary upwelling systems, Parrish et al. (1983) found a pattern of minimization of both wind-driven offshore surface flow (Ekman transport) and of wind-induced turbulence in the spawning habits of these fishes. They therefore suggest the likelihood of important effects of both processes on reproductive success. Offshore Ekman transport at a given latitude is proportional to the alongshore stress, being simply the product of the alongshore stress and the reciprocal of the local Coriolis parameter. Ekman transport (Ekman 1905) provides an acceptable description of ocean surface transport directly driven by surface wind stress at periods which are long compared to the half-pendulum day; the half-pendulum day is 2.9 actual days in length at 10° latitude but increases to infinity at the equator. Obviously, the Ekman transport description cannot be applied directly at the equator. Here we assume the Ekman transport description to be adequate for the effect of wind stress variations affecting the summary area as a whole on the monthly time scale; thus we simply divide the monthly alongshore wind stress by a characteristic value of the Coriolis parameter (we choose the local value at 10°S, i.e., 0.0000253/sec, to characterize offshore Ekman transport in response to large-scale, long period wind variations over the anchoveta reproductive habitat; this choice will affect the average magnitude but not the time series properties of the resulting indicator series, which will be identical to those of the alongshore stress series).

Wind Mixing Index

The rate at which the wind imparts mechanical energy to the ocean to produce turbulent mixing of the upper water column is roughly proportional to the third power, or "cube", of the wind speed (Elsberry and Garwood 1978). A "wind mixing index", which is simply the mean of the cube of the observed wind speeds in each monthly sample (Table 7) is presented as a guide to longer period variability in this particular process. However, it is to be noted that these series may not reflect energetic shorter-term variability which may be more crucial to reproductive success of anchovies (Husby and Nelson 1982). The hypothetical basis for interest in this process in relation to anchoveta reproductive success is Lasker's (1978) suggestion that first-feeding success of anchovy larvae may be dependent upon availability of fine scale food particle concentrations which may be dispersed by wind-driven turbulent mixing events. These occur at atmospheric storm event scales which are much shorter than one month. Furthermore, it is not the exact magnitude of mixing that is crucial according to this hypothesis, but rather the existence of time-space "survival windows" within which the rate of addition of turbulence by the wind does not reach a level that homogenizes the food particle distributions (Bakun and Parrish 1980). The wind speed level at which this occurs and the minimum required duration of the window for substantial survival to result are unclear and undoubtedly are variable functions of other factors such as water column stability, the particular food particle organism's growth rate, behavior, motility, etc. In any case, the maritime reports occur irregularly in time and space and so are not amenable to indicating durations of periods characterized by specific conditions, even if we were able to specify the required nature of the conditions. This would require utilization of a time-and-space continuous meteorological analysis procedure (Bakun 1986) which might be ineffective due to the low maritime report density in the region and particularly seaward of the region. The use of shore station data, despite interference from local topographic influences, etc., might be the best available option for indicating short time scale wind variability over the ocean habitat off Peru (see Mendo et al., this vol.).

Solar Radiation

Net incoming solar radiation, Q_S, absorbed by the ocean was estimated according to the formula:

$$Q_S = (1 - \alpha)\, Q_o\, (1 - 0.62C + 0.0019h) \qquad \ldots 2)$$

where α is the fraction of incoming radiation reflected from the sea surface, Q_0 is the sum of the direct and diffuse radiation reaching the ground under a cloudless sky, C is the observed total cloud amount in tenths of sky covered and h is the noon solar altitude. For each maritime report, the total daily direct solar radiation reaching the ground under cloudless conditions was extracted from the Smithsonian Meteorological Tables (List 1949) as a function of the date and latitude of the report, using a 4 x 4 element curvilinear interpolation on the table entries via Bessel's central difference formula and assuming the atmospheric transmission coefficient of 0.7 recommended by Seckel and Beaudry (1973). The diffuse solar radiation was estimated according to List's recommendations as follows. The solar radiation reaching the top of the atmosphere was extracted from the appropriate table. This value was decreased by 9% to allow for water vapor absorption and 2% for ozone absorption. The result is subtracted from the value previously determined for the direct radiation reaching the ground to yield the energy scattered out of the solar beam. This is reduced by 50% (to reflect the fact that half is diffused upward and therefore only half is diffused downward) to yield the total diffuse solar radiation reaching the ground. The total daily direct and diffuse radiation values corresponding to each report are then summed to yield Q_S. The remainder of the computation follows the procedures adopted by Nelson and Husby (1983). The linear cloud correction in Equation (2) is as suggested by Reed (1977), and Reed's recommendation that no correction be made for cloud amounts less than 0.25 of total sky was followed. Sea surface albedo was extracted from Payne's (1972) tables, following Nelson and Husby's (1983) algorithm which consists of entering the tables with the 0.7 atmospheric transmission coefficient reduced by a factor equal to the linear cloud correction applied in Equation (2) and the mean daily solar altitude. The possible error in the net radiation estimate introduced by using the mean daily solar altitude to indicate albedo, rather than an integration over the entire day of entries at short time intervals with instantaneous solar altitudes, is estimated to be of the order of 1%.

Radiative Heat Loss

Effective back radiation is the difference between the outgoing long-wave radiation from the sea surface, which depends on the 4th power of the absolute temperature of the sea surface, and the incoming long-wave radiation from the sky, which depends on the water vapor content of the atmosphere and on the nature of the cloud cover. Here we follow exactly the computational scheme of Nelson and Husby (1983) who used the modified Brunt equation (Brunt 1932) with the empirical constants of Budyko (1956) and the linear cloud correction formula of Reed (1976) to compute the effective back radiation (radiative heat loss), Q_B:

$$Q_B = 5.50 \times 10^{-8}\,(T_S + 273.16)^4\,(0.39 - 0.05 e_a^{1/2})\,(1 - 0.9C) \qquad \ldots 3)$$

The vapor pressure of the air, e_a, was computed according to the formula provided in the Smithsonian Meteorological Tables (List 1949) using the observed barometric pressure, and "dry bulb" and "wet bulb" air temperatures. For reports that were without an acceptable wet bulb temperature but included an acceptable dew point temperature, the vapor pressure was computed as the saturation vapor pressure at the dew point temperature using an integrated form of the Clausius-Clapeyron equation (Murray 1967).

Evaporative and Conductive Heat Losses

In estimating evaporative heat loss (latent heat transfer) and conductive heat loss (sensible heat transfer), the procedures of Nelson and Husby (1983) are again followed closely, except for a modification of the wind speed dependence in their variable transfer coefficient formulations as indicated below. The bulk aerodynamic formula for turbulent fluxes of latent and sensible heat across the air-sea interface in a neutrally stable atmospheric boundary layer (Kraus 1972) can be expressed as

$$Q_E = \rho_a L C_E (q_0 - q_{10})\,|\vec{W}_{10}| \qquad \ldots 4)$$

$$Q_C = \rho_a c_p C_H\,(T_s - T_a)\,|\vec{W}_{10}| \qquad \ldots 5)$$

where ρ_a and $|\vec{W}_{10}|$ are as in Equation (1), with ρ_a assigned the same constant value (1.22 kg/m^3) as in the stress computation. L is the latent heat of vaporization, assigned a constant value of 2.45 x 10^6 J/kg (585.3 cal/gm). c_p is the specific heat of air, assigned a constant value of 1,000 J/kg/^{o}C (0.239 cal/g/^{o}C). The empirical exchange coefficients, C_E and C_H, were assigned constant values of 0.0013 in the construction of the time series presented in Tables 10 and 11. In addition, time series based on variable transfer coefficient formulations incorporating dependencies on atmospheric stability and on wind speed were also assembled for comparison. These formulations are again those chosen by Nelson and Husby (1983) which incorporate the atmospheric stability effect according to a bulk Richardson number parameterization (Deardorff 1968); however, Nelson and Husby's wind speed dependencies were in this case modified according to the recommendations of Large and Pond (1982) who suggest an increase in C_E and C_H which is proportional to the square root of the wind speed. The specific humidities of the air in contact with the sea surface, q_0, and at 10 m or deck level, q_{10}, were computed according to

$$q \approx E \frac{e}{P} \qquad \ldots 6)$$

where E is the known ratio (a constant equal to 0.622) of the molecular weight of water vapor to the net molecular weight of dry air, e is the vapor pressure and P is the barometic pressure. For this calculation the variation in P is negligible and so a constant value of 101,325 pascals (1,013.25 mb) was assigned. The calculation of e at 10 m, or deck level, is as indicated for the radiative heat loss calculation (Equation 3). To calculate e at the sea surface, the saturation vapor pressure over pure water was computed from a formula given by Murray (1967), and reduced by 2% to account for the effect of salinity (Miyake 1952).

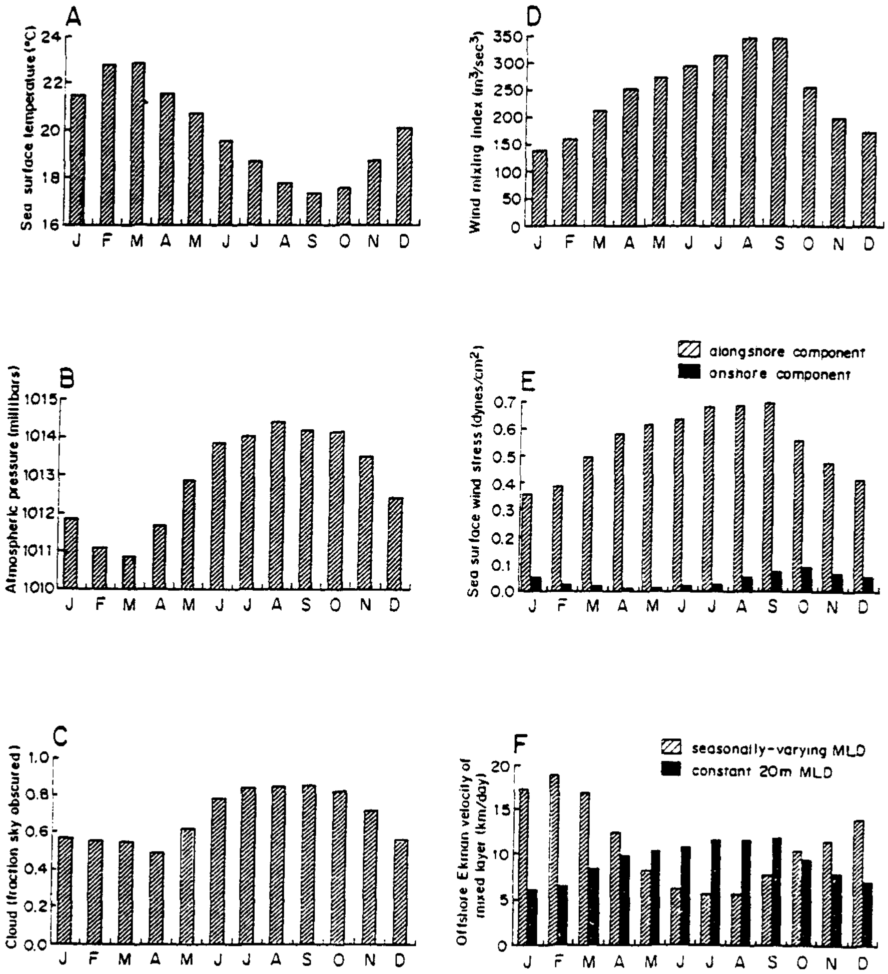

Fig. 2. Seasonal cycles. 32-yr mean monthly values.

The Seasonal Cycles

The idea of regular seasonal cycles for the coupled ocean-atmosphere system off Peru is to some degree illusory in view of the predominant influence of interyear variability in the region. However, the seasonal variation is the most cyclic and predictable of the large components of variability. It is therefore the component of variation which is most likely to be reflected in biological adaptations. Accordingly, a summary of the long-term mean monthly values of the various series (Figs. 2 and 3) serves as a useful starting point for discussion.

Being situated within the tropical band, the region experiences two passages of the sun each year; the sun is directly overhead in October and again in February-March. Also, since the earth's meteorological equator is displaced to the north of the geographical equator, the region is dominated by southern hemisphere atmospheric dynamics; thus austral winter dominates the seasonality of transfers of momentum and mechanical energy from atmosphere to ocean.

The 32-year mean monthly sea surface temperature (Fig. 2A) is at a maximum in March, coinciding with the second period of vertical sun which marks the culmination of the extended austral summer period of relatively high sun. The temperature falls to a minimum in August. The atmospheric pressure (Fig. 2B) tends to be directly out of phase, being at a minimum in the austral summer and at a maximum in the winter season. Cloudiness (Fig. 2C) lags the atmospheric pressure variation by about one month. On average less than 50% of the sky is obscured by clouds in April; this increases to greater than 85% in September.

The strength of the wind exhibits a typical southern hemisphere seasonality, being strongest in austral winter and weakest in summer. Thus the 32-year mean monthly values of the index of rate of addition of turbulent mixing energy to the water column (Fig. 2D) reach a maximum in August-September and a minimum in January. The fact that the seasonal spawning peak of anchoveta is centered within this August-September turbulent mixing maximum would indicate non-adaptation of reproductive strategy for minimization of turbulent mixing effects. This is not in accordance with the general pattern suggested by Parrish et al. (1983) as generally characterizing seasonality and geography of spawning of eastern ocean boundary anchovy populations. Although no claim is made for conclusiveness, the inference would seem to be that Lasker's (1978) hypothesis is not, at least in most years, the major factor affecting anchoveta reproductive success off Peru. Note that the level of turbulent mixing index intensity off Peru is low compared to other anchovy reproductive habitats, even at its seasonal maximum.

The alongshore component of wind stress on the sea surface is consistently equatorward: in no case in the 32-year series (Table 5) did any monthly wind mean stress value deviate from this predominently alongshore and equatorward tendency in the transfer of momentum from atmosphere to ocean. The long-term mean values of alongshore stress (Fig. 2E) follow the same seasonal pattern as the turbulent mixing index, reaching a maximum in September and a minimum in January. The 32-year mean monthly values of the onshore component of stress are small compared to those of the alongshore component, but are positive (onshore-directed) at all seasons.

Surface Ekman transport, being proportional to the alongshore stress but directed perpendicularly to the left of the stress, is thus directed offshore, with a seasonal maximum again corresponding to the seasonal spawning peak of anchoveta. This "anomaly" to the pattern of apparent minimization of offshore transport in spawning strategies of engraulids puzzled Bakun and Parrish (1982). However, Parrish et al. (1983) showed that the seasonal variation in mixed layer depth off Peru proceeds in phase with that of transport, in response to the seasonalities in turbulent mixing (Fig. 2C) and surface cooling (Fig. 2A), but has greater relative amplitude. The result is that drifting organisms which are distributed through the upper mixed layer would experience a faster net offshore drift in the thinner surface mixed layer of austral summer than in the deeper mixed layer of winter, even though the winter transport (by volume) is much larger. This is illustrated in Fig. 2F, which shows calculations of mean monthly offshore Ekman velocity of the mixed layer performed in two different ways (based on the 32-year mean monthly values of the data presented in Table 5). Firstly, the monthly estimates of offshore Ekman transport are divided by the composite mean (20 m) of the mixed layer depth values given for 2-month segments of the seasonal cycle by Parrish et al. (1983). Secondly, the same monthly estimates of offshore Ekman transport are divided by monthly mixed layer depth estimates produced by curvilinear interpolation of the 2-month seasonal segments. The effect of variable mixed layer depth on the net offshore velocity is apparent, and suggestive of adaptation of spawning seasonality for avoidance of offshore loss of larvae (for additional discussion of this aspect, see Bakun 1985). The effect of the choice of a constant or variable drag coefficient formulation in the stress computation (Equation 1) on the seasonal signal is indicated in Fig. 3A. The 32-year mean monthly Ekman transport values based on the variable coefficient formulation follow a seasonal progression which is very similar to those based on the constant coefficient formulation (i.e., presented in Table 5); however they are slightly smaller in magnitude, reflecting the effect of stability in the atmospheric boundary layer which is stabilized as the onshore-directed airflow is cooled from below while traversing the coastal upwelling zone.

Solar radiation entering the ocean (Q_S) is at a maximum during the February overhead passage of the sun (Fig. 3B). This is due to substantially reduced cloud cover relative to the November solar passage. Solar radiation is at a minimum in July, when solar altitude has just passed its June minimum, and cloudiness is approaching its winter maximum.

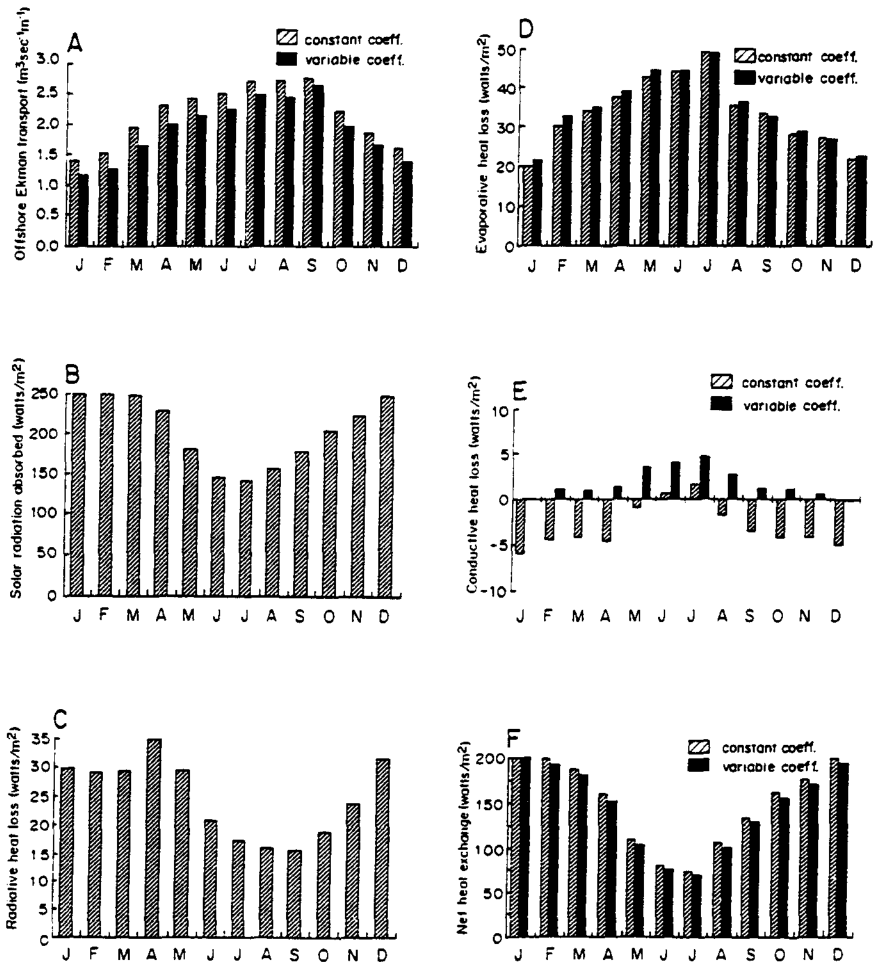

Fig. 3. Seasonal cycles. 32-yr mean monthly values. (Note that the SI-standard heat flux units, watts per square meter, may be converted to calories per square centimeter per day by multiplying by the factor 2.604)

Heat loss from the sea surface via long-wave radiation (Q_B) is only a small fraction of the short-wave radiation absorbed reflecting the area's location within the tropical band (Fig. 3C). Radiative heat loss is at a seasonal maximum during April, corresponding to the minimum in cloudiness, and at a minimum in September, corresponding to the cloudiness maximum.

Heat loss from the ocean via evaporation at the sea surface (Q_E) is at a maximum during austral winter and at a minimum during summer (Fig. 3D). The choice of constant or variable transfer coefficient has only a slight effect, with the results of the variable coefficient formulation appearing to increase very slightly in magnitude relative to those of the constant coefficient formulation toward the summer and fall seasons.

Heat loss via conduction (Q_C) is very small compared to the other heat exchange components (Fig. 3E). This is fortunate because the choice of transfer coefficient formulation completely changes the seasonal pattern. With the constant coefficient formulation, conductive heat loss is mostly negative, indicating heating of the ocean surface by contact with the atmosphere. This reflects the common situation of cool upwelling-affected surface waters being in contact with a generally warmer atmosphere. However, the strong stability of the atmosphere boundary layer inherent in this situation inhibits conductive heat transfer according to the variable transfer coefficient formulation. Thus the less common situation where the air is cooler than the water dominates the sensible heat transfer according to the variable coefficent formulation, with the result that conductive heat loss is indicated as being positive in all the 32-year composite monthly means except the summer months of January and February.

The 32-year monthly means of the time series of atmosphere-ocean heat exchange (Q_N), which represent the resultant differences between the amount of solar radiation absorbed by the ocean and the sum of the heat losses due to long-wave radiation, evaporation and conduction, indicate substantial heat gain by the ocean throughout the year (Fig. 3F). As expected, the average heat gain is greatest in austral summer, reaching values of the order of 200 watts/m^2 (413 cal cm^{-2} day^{-1}) in January, and least in winter, falling to about 70 watts/m^2 (144 cal cm^{-2} day^{-1}) in July. The constant coefficient formulations yield slightly greater numerical values of net heat exchange than do the variable coefficient formulations, mainly due to the differences in the respective indications of the conductive heat loss component discussed in the previous paragraph; however the respective seasonal progressions are very similar.

Interyear Variations

If cyclical seasonal effects are those most likely to be adapted for and incorporated in life cycle strategies of organisms, major nonseasonal variations are those most likely to cause disruptions in life cycle processes and therefore to be reflected in population variations. Very short-scale nonseasonal variations are not well resolved in these monthly composites of irregularly distributed maritime reports. However, when shorter period variability is smoothed and the cyclic seasonal effects are suppressed, nonseasonal variations of longer than annual period, which represent substantial perturbations of the environmental "normalcy" to which reproductive strategies or other life cycle strategies should have become tuned, are clearly manifested. For the purposes of this discussion, a simple 12-month running mean filter is chosen to suppress seasonalities and smooth the higher frequencies.

Problems (negative side lobes, wavelength-dependent phase shifts, etc.) with such equally-weighted moving average filters are well known (Anon. 1966). However, in this case the alternatives also present problems. We particularly wish to suppress the seasonal cycle, and so weighting the filter elements to suppress side lobes at other frequencies while increasing leakage of the seasonal frequency, is not desirable. Smoothed monthly series of anomalies from long-term monthly means (e.g., Quinn et al. 1978; McLain et al. 1985) have the property that the filtering is "nonlocal", i.e., that any value is dependent on other values in the same calendar month in temporally "distant" parts of the time series. Thus, for example, an intense warming (e.g., El Niño) occurring within a generally cool climatic period appears as a much less intense anomaly than a warming of similar magnitude within a warm period; also, the degree of indicated intensity changes whenever the length of the series used for determination of the long-term mean changes. More importantly, if the amplitude (or shape, phase, etc.) of the seasonal variation is undergoing nonseasonal variation, taking anomalies introduces spurious seasonal-scale variations into the filtered series. A "local" seasonal filter that avoids some of these problems can be based on 12th-differences, e.g., the result of subtracting from each monthly value the value for the same calendar month in the previous year, but the result is thereby transformed to annual rates of change of a property rather than the property itself, which complicates a descriptive discussion. However, the use of 12th-difference transforms is worth considering for empirical modelling efforts. For the purposes of this discussion, the simple 12-month running mean provides a "local" seasonal filter/smoother which will be familiar to many readers and adequate for a descriptive treatment.

The filtered sea surface temperature series (Fig. 4A) illustrates well the major El Niño warm events of the period: 1957-1958, 1965, 1969, 1972-1973, 1976 and 1982-1983. Generally elevated temperatures in the period between the 1976 and 1983 events are also apparent. Also apparent is the extended cold period of the mid-1950s; the indication of rise in temperature from this cold period to the peak of the 1957-1983 El Niño is comparable in total magnitude to that of the rise of the 1982-83 El Niño from the much warmer climatic base temperature level of the late 1970s.

Major features in the filtered cloud cover series (Fig. 4B) are visibly related to those in the temperature series, but not in any simple, consistent manner. Cloud cover minima often appear to coincide with the relaxation of El Niño events. An extraordinarily low degree of cloudings appears to have coincided with the return to normal sea temperatures in 1984. Another sharp cloud cover minimum coincided with the leveling off of the temperature decline following the 1957-1958 event. Likewise cloud cover maxima often appear to coincide with rapid drops of temperature into cool periods. Atmospheric pressure variations (Fig. 4C) are obviously highly inversely correlated, at these low frequencies, with those of sea surface temperature.

It is not surprising, in view of the dynamic linkage of wind to horizontal gradient of atmospheric pressure, that wind variations would be related to those of atmospheric pressure. The relation of the "wind-cubed" index of rate of addition of turbulent mixing energy to the ocean by the wind (Fig. 4D) to El Niño periods is striking. El Niño events are evidently strong wind-mixing events which, according to Lasker's (1978) scenario, would correspond to periods of high probability of starvation for first-feeding anchoveta larvae. The period during and immediately following the 1972 El Niño appears to have been characterized by an extended period of highly turbulent upper water column conditions. The period during and following the 1982-1983 event appears to have been similarly turbulent, except for a 2-month "window" of relaxed turbulent mixing index during December 1983 and January 1984 (somewhat masked by the smoothing in Fig. 4C, but evident in the unsmoothed monthly values in Table 7).

The magnitude of alongshore (equatorward) wind stress also increases during El Niño events (Fig. 4E), in agreement with Wyrtki's (1975) conclusions which were based on a summary area displaced somewhat southward along the coast (10-20°S, 70-80°W) from the one used here (Fig. 1). Thus in addition to potential increases in larval starvation due to increased destruction of food particle strata by turbulent mixing, an increase in potential offshore loss of larvae from the favorable coastal habitat is also indicated. The onshore component of surface wind stress is relatively small and consistently positive (onshore-directed) in the filtered series.

In the previous section, the effect of seasonally-varying mixed layer depth on the offshore Ekman velocity of particles which are continually mixed through the upper mixed layer was discussed (i.e., in reference to Fig. 2F). To investigate the effect on interyear time scales, filtered time series of offshore Ekman velocity were calculated as in that section, i.e., (i) assuming a constant MLD of 20 m and (ii) assuming a seasonally varying MLD derived from the values given by Parrish et al. (1983). The result indicates that, at least for the MLD values chosen, the effect of seasonally-varying mixed layer depth is such as to substantially increase on average the rate of offshore movement of passive particles in the mixed layer. If the effective mixed layer depth is increased during El Niño, as would be expected both from the effect of the propagating baroclinic wave in deepening the surface layer and also from the enhanced wind induced turbulent mixing, the effect would be to counteract the increased rate of offshore movement indicated from the Ekman transport calculations.

The effect of the choice of constant or variable drag coefficient formulation in the stress computation (Equation 1) is illustrated in Fig. 4G, where the alongshore stress variation is

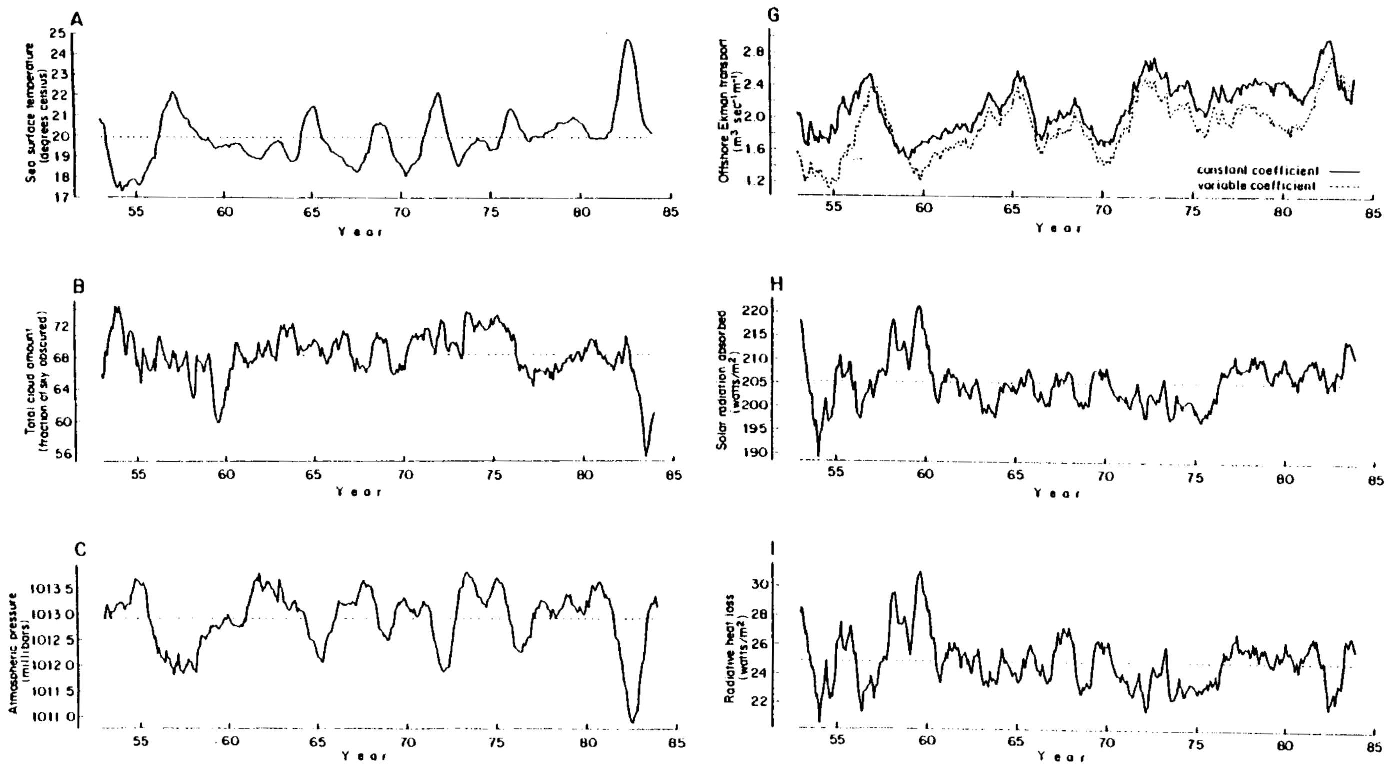

Fig. 4. Low-frequency nonseasonal variations, 12-month running means of monthly time series values. (Note that the SI-standard heat flux units, watts per square meter, may be converted to calories per square centimeter per day by multiplying by the factor 2.064.)

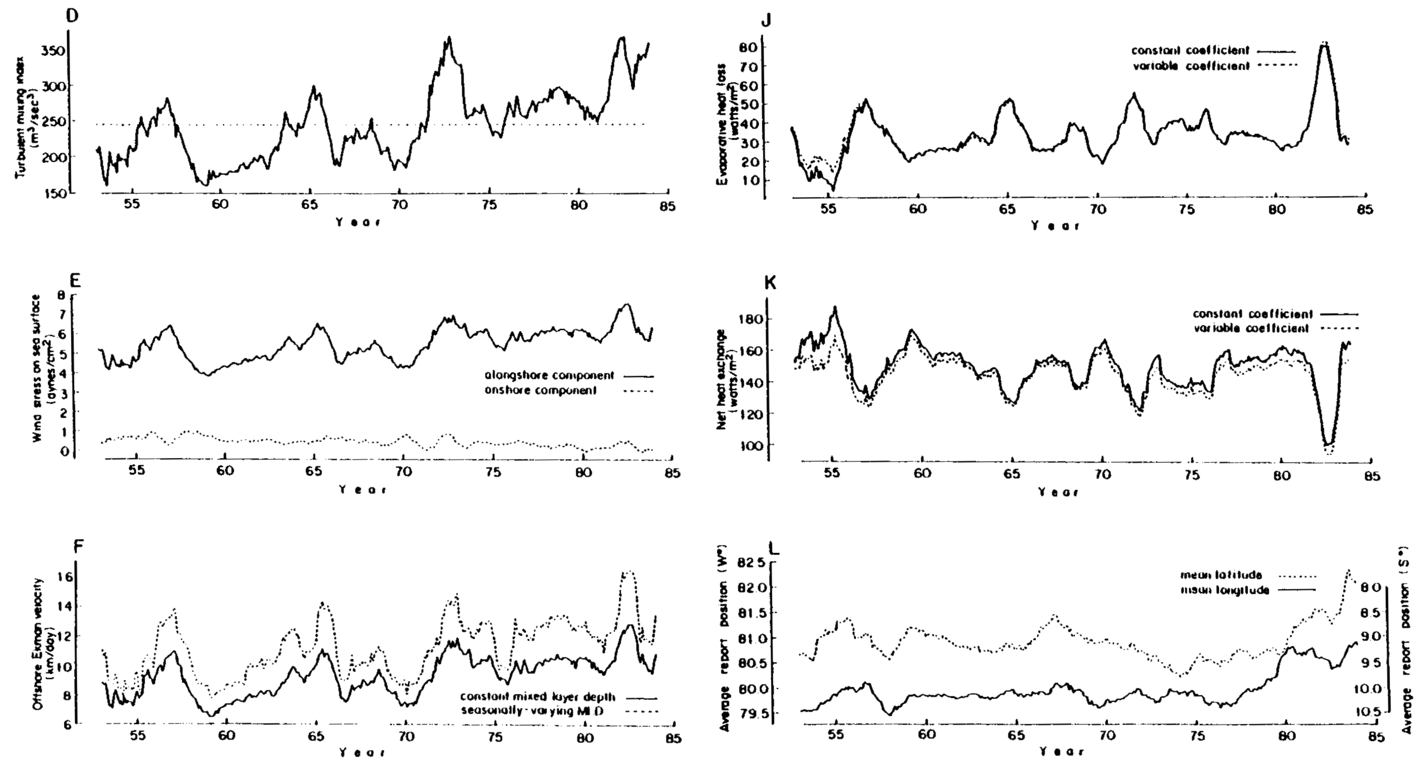

Fig. 4. Continued. Low-frequency nonseasonal variations, 12-month running means of monthly time series values. (Note that the SI-standard heat flux units, watts per square meter, may be converted to calories per square centimeter per day by multiplying by the factor 2.064.)

plotted in terms of its directly proportional transform, offshore Ekman transport. The variable coefficient formulation produces generally lower estimates of stress due to the influence of the stability of the lower atmospheric boundary layer over upwelling-affected surface waters. However the differences essentially disappear during the period of relaxation of the intense El Niños of 1957-1958 and 1982-1983. A possible explanation is the tendency for a less stable atmosphere in contact with the ocean surface due to residual warmth which would linger longer in the ocean than in the atmosphere due to the much greater heat storage capacity of water compared to that of air.

The filtered series of estimates of absorption of solar radiation by the ocean (Q_S) exhibits some interesting patterns (Fig. 4H). Since the variables that control the solar radiation estimate (Equation 2) derived from a maritime report at any given latitude are calendar date and cloud cover, it is not surprising that maxima in Fig. 4H often correspond to minima in Fig. 4B, and vice versa. However there are discernible differences between the two series that result from the interaction of the cloud cover variations with the seasonal changes in solar height in the solar radiation time series. An impressive feature in the solar radiation series is the early large-amplitude alternation consisting of deep minimum of solar radiation entering the ocean corresponding to the early part of the intense 1954-1955 cold period, followed by a sharp, highly erratic rise to a high peak in early 1960. In addition, the entire period of the 1960s and the first half of the 1970s appears to have been characterized by low absorption of solar radiation relative to the more recent period since 1976.

The long-wave radiative heat loss (Q_B) tends to be an order of magnitude smaller than the short-wave absorption, but varies very similarly (Fig. 4I). This similarity is perhaps explainable in the similar dependence of both types of estimate on cloud cover, with the sea surface temperature dependence in the long-wave radiation estimate (Equation 3) being related seasonally to the solar height dependence in the solar radiation estimate (Equation 2). There may also be some actual causal effect of the long period variations in solar radiation on the sea temperature dependence in the long-wave radiation estimate.

The filtered series of evaporative heat loss (Q_E) delineates the various El Niño episodes and the 1954-1955 cold period, in a very similar fashion to the sea surface temperature series (Fig. 4J). The long-term variation in vapor pressure difference between the sea surface and the overlying atmosphere (Equation 4) is apparently very closely linked to that of sea surface temperature. As discussed above, the wind speed dependence is also a strong function of these climate scale events. The effect of choice of constant or variable transfer coefficient apparently makes very little difference, except during the mid-1950s cold period, where increased stability of the air over the cold ocean apparently inhibited the turbulent exchange of latent heat according to the variable coefficient formulation.

The net ocean-atmosphere heat exchange series (Q_N) indicates long-term variations in net ocean heat gain such that minima are associated with El Niño episodes and maxima with cold periods. The variations appear to be controlled to a substantial extent by the evaporative heat loss (Fig. 4J). This is so because the variations in heat gain by absorption of short-wave solar radiation (Fig.4H) are partially offset by the highly correlated variations in long-wave radiative heat loss (Fig. 4I). The net effect of the choice of variable or constant transfer coefficient formulations in the evaporative and conductive components is a slight general lowering of the magnitude of net heat gain in the variable coefficient case. This difference is due primarily to the stability effect on the conductive heat loss term, as discussed in the previous section in reference to Fig. 2E, where the average change in the mean net value of this component, approximately 5 watts/m^2, corresponds in general to the approximate difference between the curves in Fig. 4K, except in the mid-1950s where stability effects on the evaporative heat loss term are appreciable.

In order to check for long-period variations in the distribution of observations within the summary area (Fig. 1), filtered series of the monthly averages of the respective latitudinal and longitudinal locations of reports were prepared (Fig. 4L). Since the coastline is oriented somewhat northwest to southeast, variations in the two curves which tend to parallel each other in the figure, will tend to yield a resultant displacement in the alongshore direction. More serious with respect to the long-term homogeneity of the monthly series herein presented are variations in Fig. 4L where the curves are changing in the opposite sense, i.e., where the net displacement of the mean position of reports is in the onshore-offshore direction; these situations are

Table 1. Numbers of observations in monthly samples used to construct time series. For each month the first number refers to observations used in constructing the values in Tables 2,4,5,6 & 7 (sea temperature, atmospheric pressure, wind stress components, and "wind cubed" index; the 2nd number refers to observations used in constructing the values in Table 4 (cloud cover); the 3rd number refers to observations used for values in Tables 8,9,10 & 11 (heat exchange components).

	Jan			*Feb*			*Mar*			*Apr*			*May*			*Jun*		
1953	21	19	19	29	29	29	22	22	19	23	23	10	33	33	33	16	16	6
1954	61	57	40	19	19	17	21	21	21	59	59	53	42	39	39	36	34	24
1955	24	22	20	35	35	29	16	15	12	9	9	5	24	24	13	35	35	30
1956	41	38	15	17	15	15	16	16	3	39	39	21	22	22	16	20	20	7
1957	32	32	32	25	24	15	98	98	47	38	38	29	25	25	21	53	52	33
1958	153	153	106	74	73	44	69	69	34	84	84	28	67	66	44	110	107	52
1959	128	125	51	162	162	49	143	138	37	115	112	37	97	96	21	67	67	43
1960	98	95	42	148	146	110	166	166	105	151	146	101	171	164	135	85	82	59
1961	148	147	127	124	124	90	115	111	94	183	180	150	89	86	66	130	128	104
1962	185	183	127	149	148	134	163	162	142	157	155	122	114	111	105	177	177	147
1963	78	76	71	103	102	102	182	181	167	180	177	170	157	156	149	185	185	185
1964	129	129	98	138	137	135	82	81	81	76	76	76	45	45	45	52	52	52
1965	59	59	58	75	71	70	137	137	137	99	99	96	139	136	136	139	139	138
1966	107	107	107	82	82	82	113	112	111	106	106	106	117	113	110	137	137	137
1967	111	109	102	60	52	52	80	80	78	147	144	144	75	74	74	66	66	66
1968	76	76	76	128	127	127	108	108	108	139	137	137	91	87	87	111	109	108
1969	67	67	67	87	84	84	134	131	131	91	91	91	56	56	56	102	102	102
1970	90	87	82	57	57	53	103	100	90	51	51	48	99	98	92	208	206	200
1971	103	101	93	81	77	75	89	89	89	53	53	52	44	44	44	22	22	21
1972	109	108	104	54	52	51	49	49	47	85	85	85	81	81	81	56	56	56
1973	55	54	40	44	44	39	89	89	89	50	50	48	58	58	56	57	54	47
1974	84	78	78	63	63	58	113	109	100	57	54	54	119	118	117	73	72	72
1975	59	57	56	73	72	69	140	140	140	99	92	90	140	138	136	116	115	114
1976	70	69	68	20	19	19	76	73	71	59	59	55	71	71	70	49	44	40
1977	51	51	51	109	106	105	79	79	73	101	99	94	93	88	87	70	70	69
1978	57	56	56	65	65	62	71	69	67	92	92	88	71	71	71	41	40	35
1979	97	96	89	58	57	51	105	104	98	85	85	77	83	80	74	48	45	34
1980	96	93	80	106	105	93	125	123	102	75	70	54	151	146	119	246	201	98
1981	116	113	85	90	89	82	139	137	124	108	103	95	115	108	79	128	124	108
1982	91	89	82	90	90	80	152	146	139	100	98	88	103	98	80	54	54	41
1983	68	64	54	126	126	116	94	91	86	76	72	61	93	92	83	61	61	55
1984	90	75	26	99	80	39	90	59	14	75	41	16	58	39	6	56	49	29
	Jul			*Aug*			*Sep*			*Oct*			*Nov*			*Dec*		
1953	10	10	9	39	35	26	29	28	25	18	18	11	24	24	18	19	18	11
1954	40	39	38	14	14	10	27	26	22	46	43	37	30	30	6	18	18	9
1955	17	17	12	37	36	21	35	35	6	45	44	34	27	27	20	13	13	5
1956	45	45	36	21	21	21	29	29	21	41	40	29	63	61	20	24	24	6
1957	27	27	11	24	24	21	64	64	38	112	110	65	100	99	53	115	115	86
1958	51	51	27	159	159	83	96	93	44	113	108	47	115	110	63	58	43	26
1959	100	100	57	103	101	39	85	81	42	74	74	21	110	110	55	114	114	85
1960	169	168	147	114	111	67	142	142	94	75	75	46	63	63	23	82	81	59
1961	108	107	82	155	155	142	153	151	141	128	127	80	197	197	192	135	133	118
1962	213	212	193	168	168	159	81	81	75	129	125	125	173	172	152	91	88	79
1963	120	120	120	70	70	70	110	110	101	70	70	70	61	61	58	56	56	53
1964	90	88	87	71	65	64	94	94	88	129	127	121	62	61	58	105	104	102
1965	92	92	92	119	117	115	99	99	98	67	67	67	177	176	176	111	111	106
1966	116	112	112	122	118	118	185	182	182	131	125	125	89	89	88	123	123	123
1967	89	87	87	67	67	67	84	84	84	76	71	71	73	73	73	99	97	97
1968	58	58	58	82	81	81	59	59	56	111	109	108	118	118	118	66	65	65
1969	70	70	70	86	84	84	108	97	92	102	102	97	137	137	127	101	101	96
1970	75	74	74	66	65	65	91	90	90	50	50	50	127	125	124	68	68	67
1971	43	43	42	58	58	54	28	28	23	51	51	47	78	78	78	34	31	30
1972	35	32	30	60	58	54	32	32	29	81	74	74	31	28	26	51	51	48
1973	81	75	74	105	92	88	89	84	82	55	54	50	100	98	98	71	71	70
1974	102	101	101	90	89	89	67	66	66	53	52	50	78	78	77	44	44	44
1975	67	66	65	53	48	47	70	68	68	70	65	60	68	68	67	88	88	88
1976	74	74	72	21	21	18	88	87	86	76	76	73	46	44	44	58	57	57
1977	55	54	53	55	51	51	73	70	68	106	104	104	183	166	163	67	59	59
1978	37	33	30	55	51	50	73	72	67	53	49	49	99	79	76	87	87	85
1979	80	75	63	117	108	90	116	109	82	84	77	53	77	75	59	39	35	26
1980	281	233	53	207	182	90	148	131	94	129	118	89	80	74	61	70	66	47
1981	169	161	78	174	159	63	122	111	92	127	115	97	174	155	142	154	147	127
1982	78	74	68	78	70	66	71	62	55	106	102	81	132	124	113	93	89	51
1983	124	121	84	145	116	46	70	48	19	156	150	90	73	73	24	96	90	32
1984	104	90	41	113	95	65	87	69	8	75	54	25	62	40	14	77	61	35

Table 2. Sea surface temperature in degrees Calsius. The standard error of the mean appears within parentheses to the right of the mean temperature value.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*
1953	21.14(.50)	23.08(.64)	24.63(.51)	24.78(.49)	22.79(.37)	20.52(.46)
1954	18.55(.33)	22.86(.46)	22.01(.42)	16.36(.29)	17.86(.23)	16.95(.25)
1955	21.72(.39)	18.50(.52)	21.01(.85)	19.01(.37)	17.89(.85)	16.67(.30)
1956	19.90(.44)	17.64(.82)	21.66(.46)	20.71(.29)	19.90(.41)	19.22(.29)
1957	19.47(.47)	24.83(.48)	25.26(.21)	24.53(.37)	24.76(.48)	23.15(.27)
1958	23.15(.11)	25.00(.19)	24.52(.25)	22.83(.30)	21.63(.35)	20.42(.18)
1959	20.45(.21)	23.08(.18)	24.49(.15)	21.54(.25)	20.90(.18)	19.26(.25)
1960	21.97(.18)	22.74(.18)	22.70(.19)	20.58(.18)	19.09(.14)	18.22(.18)
1961	22.30(.15)	23.24(.20)	21.61(.21)	19.94(.15)	20.24(.21)	18.67(.15)
1962	21.29(.14)	22.12(.18)	20.37(.18)	19.41(.18)	18.68(.18)	18.92(.12)
1963	20.72(.24)	22.67(.17)	22.15(.16)	20.21(.17)	21.01(.13)	18.98(.10)
1964	21.44(.12)	22.41(.14)	20.91(.22)	20.66(.37)	18.38(.26)	17.35(.24)
1965	21.75(.26)	23.09(.27)	23.96(.15)	24.54(.21)	24.08(.20)	22.11(.14)
1966	22.09(.20)	23.62(.20)	21.96(.25)	20.85(.24)	19.88(.24)	18.67(.16)
1967	20.01(.22)	22.12(.22)	21.86(.23)	20.61(.19)	19.11(.24)	18.13(.30)
1968	19.67(.21)	22.21(.21)	21.78(.22)	18.60(.20)	18.49(.30)	17.31(.20)
1969	22.28(.23)	22.36(.23)	24.25(.18)	23.51(.23)	22.94(.25)	20.92(.22)
1970	21.71(.26)	21.94(.43)	22.51(.26)	20.40(.33)	18.73(.21)	16.85(.14)
1971	19.70(.19)	20.34(.29)	19.70(.25)	21.63(.36)	19.80(.32)	18.46(.46)
1972	20.94(.25)	24.38(.41)	25.17(.37)	22.97(.24)	23.05(.22)	21.68(.24)
1973	24.22(.25)	24.40(.39)	22.52(.20)	19.54(.31)	19.16(.37)	17.36(.35)
1974	20.72(.30)	22.00(.36)	22.10(.31)	21.35(.36)	21.36(.24)	19.51(.19)
1975	21.25(.28)	22.41(.24)	23.41(.19)	22.21(.27)	20.81(.21)	18.67(.18)
1976	21.16(.30)	23.38(.64)	22.96(.33)	22.45(.35)	21.64(.28)	21.23(.30)
1977	23.69(.22)	23.46(.19)	22.44(.32)	20.44(.28)	19.77(.24)	19.66(.27)
1978	21.06(.24)	23.46(.25)	22.57(.25)	22.69(.32)	20.07(.34)	19.95(.49)
1979	22.42(.19)	23.11(.28)	23.62(.22)	22.71(.26)	20.37(.31)	20.61(.45)
1980	21.69(.25)	23.22(.21)	24.21(.21)	22.48(.29)	21.81(.17)	20.84(.13)
1981	20.90(.26)	22.80(.22)	22.10(.24)	20.99(.28)	20.73(.20)	19.44(.16)
1982	21.33(.22)	22.62(.30)	21.65(.23)	21.20(.24)	21.01(.22)	21.15(.41)
1983	26.42(.19)	27.38(.19)	27.99(.14)	27.93(.20)	27.72(.15)	25.93(.30)
1984	22.13(.22)	22.78(.29)	21.92(.26)	20.95(.33)	19.17(.31)	19.49(.28)
	Jul	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1953	19.78(.27)	19.06(.21)	18.20(.34)	18.24(.35)	18.72(.40)	18.81(.41)
1954	14.60(.35)	15.57(.41)	14.91(.31)	14.22(.29)	17.11(.26)	19.24(.54)
1955	17.68(.53)	15.54(.45)	15.71(.28)	14.69(.37)	17.09(.24)	18.12(.37)
1956	18.94(.24)	17.65(.37)	17.48(.29)	16.75(.19)	18.38(.29)	19.23(.40)
1957	22.43(.34)	19.28(.34)	18.94(.19)	19.23(.17)	19.07(.16)	20.75(.16)
1958	19.63(.26)	17.37(.10)	17.80(.15)	17.90(.13)	18.98(.18)	20.25(.31)
1959	17.55(.15)	16.80(.12)	16.64(.18)	17.77(.20)	19.04(.20)	19.35(.15)
1960	17.65(.10)	17.42(.12)	17.17(.11)	17.53(.18)	18.78(.24)	20.59(.17)
1961	18.04(.22)	17.62(.11)	16.87(.11)	17.36(.16)	18.54(.14)	19.39(.17)
1962	17.30(.09)	17.27(.10)	16.77(.10)	16.89(.10)	18.08(.12)	19.49(.21)
1963	18.70(.13)	18.24(.17)	18.00(.11)	17.55(.16)	18.54(.28)	19.72(.17)
1964	17.10(.18)	16.11(.20)	16.11(.14)	16.40(.15)	18.31(.32)	19.76(.19)
1965	20.59(.20)	20.00(.20)	17.79(.16)	18.26(.23)	18.76(.13)	21.49(.15)
1966	18.00(.12)	16.75(.13)	16.81(.10)	17.37(.12)	18.13(.17)	19.77(.20)
1967	17.40(.16)	16.46(.17)	15.76(.13)	16.09(.21)	16.90(.18)	18.22(.21)
1968	17.64(.23)	17.05(.17)	18.26(.38)	17.65(.17)	17.67(.16)	20.82(.24)
1969	18.44(.20)	18.01(.17)	17.36(.19)	18.24(.16)	18.39(.13)	19.49(.15)
1970	15.72(.12)	16.19(.13)	16.33(.28)	16.36(.25)	17.94(.16)	18.29(.21)
1971	18.00(.28)	17.27(.23)	16.32(.26)	17.05(.27)	18.34(.15)	19.81(.35)
1972	21.18(.36)	21.77(.23)	19.29(.36)	19.17(.25)	20.61(.32)	21.73(.31)
1973	16.88(.32)	16.04(.16)	15.80(.22)	16.11(.31)	17.27(.24)	19.01(.30)
1974	18.12(.15)	17.48(.15)	16.70(.31)	16.91(.32)	18.96(.23)	19.83(.35)
1975	18.46(.25)	17.68(.36)	15.71(.24)	15.59(.20)	16.24(.15)	18.74(.24)
1976	21.18(.20)	19.51(.55)	19.00(.23)	19.19(.25)	20.04(.23)	21.46(.15)
1977	18.54(.25)	17.23(.22)	17.21(.28)	18.49(.28)	18.95(.16)	19.45(.24)
1978	18.49(.35)	16.91(.33)	17.27(.25)	18.11(.25)	19.40(.30)	20.49(.24)
1979	18.73(.25)	18.30(.26)	19.01(.28)	18.53(.23)	19.25(.27)	21.04(.38)
1980	20.04(.11)	18.35(.13)	17.77(.15)	18.39(.23)	18.95(.27)	20.21(.21)
1981	18.08(.17)	18.24(.11)	17.67(.24)	17.86(.23)	18.98(.15)	20.29(.15)
1982	19.65(.18)	18.34(.23)	19.00(.36)	20.61(.22)	23.03(.17)	25.19(.21)
1983	23.24(.23)	21.26(.21)	19.57(.25)	19.89(.14)	20.25(.22)	21.54(.27)
1984	19.52(.23)	18.37(.13)	18.44(.18)	18.27(.28)	19.70(.31)	20.20(.31)

Table 3. Total cloud amount. Values indicate mean fraction of sky obscured. The standard error of the mean appears in parentheses to the right of each mean value.

	Jan	Feb	Mar	Apr	May	Jun
1953	.66(.06)	.58(.06)	.43(.06)	.43(.08)	.54(.06)	.76(.10)
1954	.59(.05)	.75(.05)	.69(.07)	.35(.04)	.85(.05)	.74(.07)
1955	.55(.07)	.61(.06)	.60(.09)	.06(.04)	.69(.08)	.90(.04)
1956	.66(.05)	.46(.10)	.40(.06)	.53(.06)	.65(.08)	.89(.06)
1957	.48(.07)	.80(.05)	.56(.03)	.57(.05)	.55(.06)	.76(.04)
1958	.60(.03)	.68(.03)	.63(.03)	.32(.04)	.54(.04)	.83(.03)
1959	.40(.03)	.58(.02)	.66(.02)	.60(.03)	.83(.03)	.78(.04)
1960	.50(.03)	.50(.03)	.38(.02)	.44(.03)	.51(.03)	.63(.05)
1961	.65(.03)	.44(.03)	.65(.03)	.50(.03)	.49(.04)	.79(.03)
1962	.55(.02)	.54(.03)	.48(.03)	.56(.03)	.53(.04)	.79(.03)
1963	.50(.04)	.52(.03)	.61(.02)	.52(.03)	.66(.03)	.81(.02)
1964	.64(.03)	.66(.03)	.57(.04)	.51(.04)	.72(.06)	.63(.06)
1965	.54(.04)	.49(.04)	.61(.02)	.60(.03)	.63(.03)	.64(.03)
1966	.56(.03)	.44(.03)	.57(.03)	.45(.03)	.62(.03)	.76(.03)
1967	.72(.03)	.51(.05)	.56(.03)	.51(.03)	.46(.04)	.82(.04)
1968	.52(.04)	.52(.03)	.45(.03)	.38(.03)	.65(.04)	.75(.03)
1969	.57(.04)	.55(.04)	.58(.03)	.57(.04)	.70(.05)	.81(.03)
1970	.59(.04)	.43(.04)	.37(.03)	.43(.05)	.62(.04)	.81(.02)
1971	.51(.03)	.58(.04)	.48(.03)	.52(.05)	.68(.06)	.85(.06)
1972	.53(.04)	.49(.04)	.64(.03)	.53(.04)	.69(.04)	.78(.04)
1973	.67(.03)	.61(.05)	.60(.04)	.49(.04)	.40(.05)	.70(.05)
1974	.59(.03)	.52(.04)	.53(.03)	.53(.05)	.77(.03)	.89(.02)
1975	.69(.04)	.50(.04)	.60(.02)	.54(.03)	.72(.03)	.86(.03)
1976	.61(.04)	.59(.08)	.63(.03)	.55(.05)	.62(.04)	.87(.04)
1977	.54(.05)	.68(.03)	.55(.04)	.34(.03)	.53(.04)	.71(.04)
1978	.53(.04)	.65(.04)	.45(.04)	.57(.04)	.54(.05)	.68(.07)
1979	.50(.03)	.53(.04)	.56(.03)	.44(.03)	.67(.04)	.79(.05)
1980	.57(.03)	.53(.03)	.58(.03)	.48(.04)	.57(.03)	.80(.02)
1981	.66(.03)	.63(.03)	.51(.03)	.57(.03)	.66(.03)	.80(.03)
1982	.60(.03)	.58(.03)	.55(.03)	.52(.03)	.58(.04)	.84(.04)
1983	.52(.04)	.47(.02)	.63(.03)	.70(.03)	.75(.03)	.74(.04)
1984	.42(.04)	.43(.03)	.45(.03)	.40(.04)	.34(.05)	.74(.04)
	Jul	Aug	Sep	Oct	Nov	Dec
1953	.65(.14)	.91(.04)	.74(.07)	.74(.07)	.81(.06)	.67(.07)
1954	.79(.05)	.88(.07)	.92(.05)	.89(.04)	.72(.05)	.75(.08)
1955	.97(.02)	.90(.04)	.90(.04)	.80(.05)	.61(.08)	.44(.10)
1956	.85(.05)	.82(.08)	.84(.05)	.82(.05)	.73(.05)	.49(.08)
1957	.79(.06)	.72(.08)	.85(.04)	.72(.03)	.72(.03)	.64(.03)
1958	.79(.05)	.80(.03)	.90(.02)	.81(.03)	.52(.04)	.45(.06)
1959	.78(.03)	.78(.03)	.79(.04)	.79(.03)	.63(.04)	.51(.03)
1960	.72(.03)	.81(.03)	.90(.02)	.89(.03)	.63(.05)	.67(.04)
1961	.94(.01)	.83(.02)	.90(.02)	.78(.03)	.61(.02)	.60(.03)
1962	.90(.02)	.93(.02)	.86(.03)	.88(.02)	.77(.02)	.46(.04)
1963	.80(.03)	.80(.04)	.88(.02)	.82(.04)	.77(.04)	.68(.05)
1964	.87(.03)	.87(.03)	.86(.03)	.88(.02)	.77(.04)	.51(.03)
1965	.88(.03)	.90(.02)	.92(.02)	.86(.03)	.75(.02)	.61(.03)
1966	.77(.03)	.83(.03)	.85(.02)	.89(.02)	.83(.03)	.61(.03)
1967	.88(.03)	.91(.03)	.84(.03)	.85(.04)	.86(.03)	.47(.04)
1968	.80(.05)	.93(.02)	.88(.03)	.83(.03)	.76(.03)	.50(.04)
1969	.86(.04)	.83(.03)	.91(.02)	.82(.03)	.68(.03)	.56(.04)
1970	.87(.04)	.91(.03)	.85(.03)	.95(.02)	.59(.03)	.64(.04)
1971	.94(.02)	.88(.03)	.91(.03)	.85(.05)	.65(.04)	.65(.06)
1972	.83(.05)	.80(.04)	.87(.04)	.78(.04)	.86(.05)	.67(.05)
1973	.82(.03)	.91(.02)	.87(.03)	.80(.04)	.81(.03)	.72(.04)
1974	.91(.02)	.89(.03)	.88(.03)	.75(.05)	.72(.04)	.57(.05)
1975	.86(.03)	.89(.03)	.89(.03)	.77(.04)	.78(.04)	.64(.04)
1976	.80(.04)	.93(.03)	.77(.03)	.81(.03)	.78(.04)	.53(.04)
1977	.89(.03)	.86(.04)	.83(.04)	.81(.03)	.72(.02)	.41(.05)
1978	.95(.01)	.84(.04)	.80(.04)	.81(.04)	.68(.04)	.50(.03)
1979	.85(.03)	.81(.03)	.83(.03)	.81(.03)	.80(.03)	.49(.06)
1980	.90(.01)	.90(.02)	.81(.02)	.82(.02)	.69(.04)	.48(.04)
1981	.87(.02)	.83(.02)	.92(.02)	.67(.03)	.63(.03)	.51(.03)
1982	.80(.04)	.88(.03)	.82(.03)	.76(.03)	.75(.03)	.58(.03)
1983	.72(.03)	.68(.03)	.66(.06)	.80(.02)	.58(.04)	.49(.04)
1984	.81(.03)	.75(.03)	.86(.03)	.91(.03)	.70(.05)	.52(.04)

Table 4. Atmospheric pressure at sea level. Add 1000.0 to the mean values in the table to yield pressure in millibars. The standard error of the mean appears in parentheses to the right of each mean value; the standard errors are given (directly) in millibars.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*
1953	11.2(.3)	10.4(.1)	11.1(.3)	13.2(.5)	12.5(.2)	14.5(.5)
1954	12.3(.2)	12.2(.4)	10.2(.4)	11.3(.3)	13.5(.3)	14.7(.3)
1955	12.5(.3)	10.9(.2)	10.4(.4)	11.9(.5)	13.6(.2)	15.2(.2)
1956	11.5(.2)	10.7(.4)	11.1(.3)	10.9(.3)	12.0(.2)	10.0(.6)
1957	12.8(.2)	8.6(.3)	10.9(.3)	9.9(.3)	12.3(.2)	12.3(.2)
1958	11.9(.2)	11.5(.2)	7.2(.4)	9.8(.3)	11.5(.2)	13.2(.1)
1959	12.0(.2)	10.9(.1)	11.5(.2)	11.2(.1)	13.3(.2)	14.2(.2)
1960	11.6(.2)	11.5(.2)	11.3(.2)	11.5(.1)	12.7(.1)	13.7(.2)
1961	10.6(.4)	10.6(.2)	10.6(.2)	11.2(.4)	12.9(.1)	13.6(.2)
1962	13.0(.1)	11.8(.2)	12.0(.1)	12.8(.2)	14.0(.2)	15.3(.1)
1963	12.9(.2)	13.6(.2)	11.2(.1)	13.5(.4)	13.2(.1)	14.2(.1)
1964	12.3(.1)	10.5(.1)	11.2(.2)	12.2(.2)	12.7(.4)	14.2(.2)
1965	11.7(.1)	10.2(.2)	11.0(.2)	11.5(.1)	11.3(.2)	12.9(.2)
1966	10.6(.2)	10.2(.2)	10.2(.1)	11.8(.2)	13.2(.1)	14.6(.1)
1967	11.5(.2)	12.3(.2)	12.0(.2)	11.3(.2)	13.1(.2)	14.3(.2)
1968	11.3(.2)	11.7(.1)	12.6(.2)	12.9(.1)	14.3(.2)	15.6(.1)
1969	11.2(.3)	9.6(.1)	11.4(.2)	11.3(.1)	11.5(.2)	13.5(.2)
1970	12.8(.2)	11.0(.2)	11.8(.1)	11.7(.2)	14.5(.2)	14.4(.1)
1971	11.9(.2)	10.8(.2)	10.8(.2)	12.3(.2)	13.8(.3)	15.3(.4)
1972	10.9(.2)	11.0(.3)	10.3(.2)	11.5(.2)	11.8(.2)	12.1(.2)
1973	10.5(.4)	11.8(.2)	10.7(.2)	11.5(.3)	13.0(.3)	14.5(.2)
1974	11.9(.5)	11.8(.2)	12.5(.2)	12.6(.3)	13.7(.3)	14.2(.2)
1975	11.5(.3)	11.9(.2)	11.4(.1)	11.9(.2)	13.5(.1)	14.0(.1)
1976	12.1(.3)	11.6(.7)	10.6(.1)	11.9(.2)	12.5(.2)	12.0(.2)
1977	10.4(.3)	11.2(.1)	10.0(.2)	12.0(.4)	12.6(.2)	13.7(.2)
1978	13.9(.3)	10.1(.7)	12.0(.2)	12.3(.2)	12.8(.2)	15.0(.3)
1979	12.2(.1)	11.9(.3)	11.4(.2)	11.0(.3)	13.3(.3)	15.5(.5)
1980	11.9(.2)	12.3(.2)	9.3(.2)	10.5(.2)	12.9(.2)	14.5(.3)
1981	13.9(.3)	10.8(.2)	11.4(.2)	12.1(.2)	14.3(.2)	13.8(.4)
1982	12.6(.5)	11.4(.2)	10.4(.2)	12.1(.2)	12.6(.2)	12.9(.3)
1983	9.1(.3)	9.7(.2)	9.1(.2)	9.5(.2)	9.6(.3)	11.6(.2)
1984	12.5(.2)	10.7(.3)	10.7(.5)	13.1(.3)	13.7(.7)	13.9(.2)

	Jul	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1953	13.7(.5)	13.4(.2)	13.0(.2)	15.0(.5)	14.0(.3)	13.2(.4)
1954	13.8(.3)	14.3(.4)	13.8(.3)	14.8(.2)	14.5(.2)	13.0(.3)
1955	15.7(.3)	15.1(.3)	15.4(.3)	16.1(.3)	14.0(.2)	13.1(.5)
1956	14.9(.3)	13.7(.4)	14.4(.3)	14.1(.2)	14.2(.5)	9.4(.6)
1957	13.0(.3)	14.0(.3)	12.5(.3)	13.4(.2)	12.8(.2)	12.2(.2)
1958	14.1(.3)	13.8(.2)	14.0(.3)	12.7(.2)	12.8(.2)	10.6(1.7)
1959	13.6(.1)	14.1(.2)	13.1(.2)	13.7(.2)	13.3(.2)	12.2(.3)
1960	14.5(.1)	14.5(.2)	14.1(.1)	14.0(.2)	13.1(.2)	13.5(.3)
1961	14.4(.2)	14.4(.1)	14.7(.1)	13.5(.1)	14.7(.2)	13.2(.1)
1962	14.4(.1)	15.2(.2)	13.9(.3)	15.3(.2)	10.6(1.4)	13.8(.2)
1963	14.3(.2)	13.6(.3)	13.8(.4)	14.4(.1)	15.4(.4)	12.4(.2)
1964	14.8(.1)	14.8(.2)	14.2(.2)	14.3(.2)	13.1(.2)	13.2(.1)
1965	12.6(.2)	14.0(.2)	14.1(.2)	13.9(.2)	12.1(.2)	11.6(.1)
1966	14.0(.1)	14.9(.1)	14.8(.1)	14.1(.2)	13.6(.2)	12.3(.1)
1967	14.2(.2)	14.5(.2)	15.2(.2)	14.0(.2)	13.4(.2)	13.0(.2)
1968	14.8(.2)	15.2(.1)	14.0(.3)	13.5(.2)	14.1(.1)	12.6(.2)
1969	14.3(.2)	14.9(.2)	13.0(.1)	13.8(.1)	13.2(.2)	12.2(.1)
1970	15.5(.1)	14.4(.2)	13.8(.2)	13.9(.3)	13.9(.1)	11.0(.2)
1971	13.7(.3)	14.3(.7)	14.5(.4)	15.3(.2)	14.0(.1)	12.3(.3)
1972	12.5(.6)	12.8(.3)	12.9(.3)	13.1(.2)	12.2(.3)	11.8(.6)
1973	14.7(.4)	14.8(.2)	15.2(.3)	15.1(.2)	14.3(.2)	14.8(.2)
1974	13.8(.4)	14.7(.2)	14.9(.2)	14.0(.2)	13.7(.1)	12.6(.2)
1975	15.2(.2)	15.1(.3)	15.5(.2)	15.3(.2)	15.1(.2)	13.5(.2)
1976	13.3(.2)	14.6(.6)	13.3(.4)	13.7(.3)	13.9(.2)	10.4(.2)
1977	13.5(.3)	14.3(.2)	14.7(.2)	14.2(.2)	13.7(.2)	12.4(.2)
1978	13.9(.4)	14.1(.2)	14.5(.2)	13.8(.2)	12.3(.2)	12.3(.2)
1979	14.9(.2)	14.2(.3)	14.7(.3)	14.8(.2)	14.1(.3)	12.5(.9)
1980	15.1(.2)	15.2(.2)	14.1(.4)	13.8(.3)	13.8(.2)	13.7(.5)
1981	15.0(.3)	16.0(.2)	14.8(.2)	13.9(.2)	13.4(.2)	11.9(.1)
1982	12.0(.2)	12.9(.2)	14.1(.3)	12.9(.2)	10.6(.2)	10.0(.2)
1983	11.8(.2)	14.2(.4)	15.0(.5)	13.6(.2)	13.3(.7)	14.2(.4)
1984	12.6(.4)	15.3(.3)	14.8(.5)	14.5(.3)	14.2(.1)	11.8(.3)

Table 5. Alongshore component (positive equatorward) of wind stress on the sea surface. Units are dynes per square centimeter. The standard error of the mean appears in parentheses to the right of the mean alongshore stress value. Values in this table multiplied by the factor 3.95 (see text) yield offshore Ekman transport in cubic meters per second across each meter width.

	Jan	Feb	Mar	Apr	May	Jun
1953	.36(.06)	.32(.05)	.44(.07)	.99(.20)	.83(.09)	.37(.10)
1954	.24(.03)	.41(.14)	.10(.02)	.46(.05)	.56(.08)	.46(.08)
1955	.40(.09)	.16(.03)	.53(.18)	.18(.08)	.63(.11)	.45(.09)
1956	.16(.02)	.25(.07)	.67(.10)	.83(.09)	.85(.13)	.50(.05)
1957	.31(.06)	.53(.11)	.76(.05)	.86(.10)	.57(.06)	.76(.07)
1958	.40(.05)	.42(.05)	.45(.05)	.61(.06)	.57(.07)	.46(.04)
1959	.34(.03)	.28(.02)	.40(.03)	.42(.04)	.30(.03)	.59(.07)
1960	.23(.03)	.27(.02)	.41(.03)	.49(.04)	.53(.09)	.45(.04)
1961	.20(.02)	.27(.03)	.39(.04)	.48(.03)	.70(.06)	.48(.05)
1962	.42(.02)	.34(.03)	.47(.03)	.52(.04)	.51(.04)	.60(.04)
1963	.32(.04)	.39(.03)	.61(.03)	.47(.03)	.59(.04)	.33(.03)
1964	.49(.04)	.44(.03)	.51(.05)	.71(.07)	.63(.07)	.58(.12)
1965	.29(.04)	.40(.05)	.40(.03)	.53(.06)	.97(.07)	.58(.04)
1966	.60(.04)	.61(.06)	.46(.04)	.75(.06)	.59(.05)	.62(.04)
1967	.40(.04)	.36(.04)	.29(.03)	.30(.03)	.37(.04)	.71(.10)
1968	.15(.02)	.40(.05)	.36(.03)	.36(.03)	.34(.05)	.65(.05)
1969	.29(.04)	.26(.04)	.47(.04)	.56(.04)	.45(.07)	.89(.08)
1970	.33(.04)	.16(.05)	.40(.05)	.56(.06)	.55(.05)	.52(.04)
1971	.17(.04)	.36(.04)	.34(.03)	.59(.08)	.43(.07)	.73(.23)
1972	.29(.03)	.34(.04)	.56(.11)	.55(.04)	.42(.04)	.67(.08)
1973	.57(.06)	.38(.05)	.73(.05)	.68(.08)	.67(.11)	.51(.07)
1974	.32(.04)	.42(.05)	.48(.04)	.68(.07)	.71(.05)	.66(.07)
1975	.40(.04)	.35(.04)	.72(.05)	.63(.05)	.74(.04)	.63(.06)
1976	.21(.04)	.17(.04)	.51(.05)	.77(.07)	.72(.07)	.56(.08)
1977	.32(.06)	.56(.06)	.38(.04)	.57(.05)	.47(.05)	.67(.05)
1978	.37(.05)	.47(.06)	.62(.07)	.71(.08)	.59(.07)	.72(.12)
1979	.49(.05)	.54(.09)	.54(.04)	.68(.05)	.69(.07)	.92(.14)
1980	.44(.04)	.47(.05)	.49(.04)	.49(.05)	.89(.07)	.58(.03)
1981	.52(.04)	.30(.03)	.46(.04)	.54(.04)	.53(.05)	.84(.08)
1982	.35(.04)	.47(.04)	.63(.04)	.55(.04)	.65(.06)	.91(.12)
1983	.69(.06)	.66(.04)	.46(.05)	.74(.08)	.75(.06)	1.07(.09)
1984	.26(.04)	.53(.11)	.80(.13)	.31(.11)	.83(.18)	.87(.13)

	Jul	Aug	Sep	Oct	Nov	Dec
1953	.70(.22)	.36(.05)	.46(.06)	.53(.08)	.62(.08)	.27(.05)
1954	.52(.07)	.89(.21)	.83(.09)	.24(.02)	.30(.04)	.20(.04)
1955	.46(.09)	.88(.14)	.66(.10)	.65(.12)	.60(.08)	.11(.04)
1956	.69(.09)	.52(.13)	.64(.05)	.50(.08)	.45(.04)	.45(.08)
1957	1.01(.11)	.54(.08)	.75(.07)	.56(.06)	.44(.04)	.56(.04)
1958	.51(.05)	.71(.06)	.49(.04)	.43(.04)	.26(.03)	.39(.05)
1959	.38(.04)	.53(.04)	.48(.07)	.44(.05)	.31(.03)	.23(.03)
1960	.59(.05)	.55(.04)	.51(.04)	.48(.06)	.34(.03)	.36(.04)
1961	.67(.06)	.50(.04)	.50(.04)	.40(.03)	.38(.02)	.31(.03)
1962	.60(.04)	.49(.04)	.60(.06)	.49(.04)	.51(.04)	.23(.02)
1963	.54(.05)	.48(.06)	.72(.05)	.72(.11)	.53(.06)	.36(.04)
1964	.62(.05)	.71(.09)	.73(.08)	.57(.04)	.36(.05)	.42(.04)
1965	.63(.05)	.84(.07)	.87(.07)	.60(.07)	.49(.03)	.49(.04)
1966	.76(.04)	.74(.06)	.59(.03)	.52(.04)	.26(.03)	.26(.02)
1967	.54(.05)	.72(.07)	.74(.09)	.73(.09)	.46(.05)	.55(.06)
1968	.90(.10)	.72(.08)	.64(.08)	.59(.03)	.51(.03)	.62(.08)
1969	.58(.06)	.71(.08)	.59(.05)	.42(.04)	.28(.03)	.37(.04)
1970	.57(.06)	.52(.05)	.45(.04)	.50(.07)	.41(.03)	.27(.05)
1971	.46(.08)	.77(.11)	.64(.12)	.71(.08)	.43(.05)	.49(.09)
1972	.90(.11)	.81(.10)	1.32(.19)	.49(.05)	.35(.04)	.72(.15)
1973	.70(.11)	1.16(.12)	1.01(.11)	.71(.09)	.58(.05)	.37(.06)
1974	.73(.05)	.64(.08)	.72(.07)	.67(.07)	.68(.05)	.45(.06)
1975	.64(.07)	.91(.10)	.73(.05)	.51(.05)	.36(.04)	.35(.05)
1976	.59(.05)	.69(.16)	.80(.06)	.67(.06)	.64(.06)	.52(.06)
1977	.94(.11)	.83(.10)	.47(.06)	.46(.04)	.57(.04)	.55(.06)
1978	.87(.14)	.69(.08)	.73(.09)	.54(.06)	.51(.06)	.47(.05)
1979	.65(.07)	.66(.09)	.71(.07)	.65(.05)	.54(.05)	.46(.07)
1980	1.01(.04)	.74(.04)	.75(.06)	.65(.05)	.47(.04)	.49(.06)
1981	.77(.07)	.64(.04)	.85(.09)	.41(.04)	.57(.04)	.42(.03)
1982	.89(.08)	.63(.06)	.96(.12)	.84(.06)	.73(.04)	.66(.05)
1983	.86(.06)	.69(.06)	.77(.07)	.60(.05)	.38(.10)	.23(.05)
1984	.61(.06)	.76(.06)	.64(.07)	.60(.04)	.86(.06)	.58(.05)

Table 6. Onshore component of wind stress on the sea surface. Units are dynes per square centimeter. The standard error of the mean appears in parentheses to the right of each mean onshore stress value.

	Jan	Feb	Mar	Apr	May	Jun
1953	.10(.03)	.02(.03)	.00(.05)	-.12(.04)	.02(.04)	-.06(.05)
1954	.04(.01)	.07(.05)	.00(.01)	.10(.02)	-.04(.03)	.04(.02)
1955	-.04(.03)	.02(.01)	.19(.07)	.09(.08)	-.01(.03)	-.01(.03)
1956	.06(.03)	.08(.03)	.08(.08)	.01(.04)	.01(.05)	.10(.04)
1957	.05(.02)	-.06(.05)	-.06(.02)	-.04(.03)	.00(.04)	.06(.03)
1958	.07(.01)	.08(.02)	.09(.02)	.01(.02)	.02(.02)	.08(.02)
1959	.05(.01)	.07(.01)	.01(.02)	.06(.01)	.04(.02)	.17(.03)
1960	.07(.01)	.04(.01)	.05(.01)	.04(.02)	.03(.01)	.02(.02)
1961	.03(.01)	.01(.01)	.06(.02)	.05(.01)	.03(.02)	.04(.02)
1962	.08(.01)	.01(.02)	.04(.01)	.02(.02)	.02(.02)	-.03(.01)
1963	.06(.01)	.02(.02)	.08(.01)	.01(.01)	.01(.02)	.01(.01)
1964	.05(.02)	.03(.01)	.04(.02)	-.07(.03)	.00(.04)	.06(.03)
1965	.06(.02)	.05(.02)	.01(.01)	.06(.02)	-.08(.03)	.03(.02)
1966	.05(.02)	.06(.02)	.09(.03)	-.06(.02)	.03(.02)	.06(.02)
1967	.02(.02)	.08(.02)	.02(.02)	.03(.01)	.09(.02)	.08(.05)
1968	.03(.01)	.02(.02)	.04(.01)	.02(.01)	.01(.03)	.01(.02)
1969	.04(.01)	.04(.02)	.00(.01)	.03(.02)	.05(.03)	-.03(.03)
1970	.04(.02)	-.08(.05)	.05(.02)	.10(.03)	.08(.02)	.03(.01)
1971	.05(.02)	.04(.02)	.00(.02)	.03(.04)	-.03(.02)	-.08(.07)
1972	.04(.01)	-.06(.05)	-.06(.07)	.03(.02)	.00(.02)	.06(.04)
1973	.13(.03)	.07(.02)	-.02(.02)	.13(.04)	-.02(.04)	.15(.05)
1974	.04(.02)	.02(.02)	-.04(.02)	.02(.04)	-.01(.02)	.03(.03)
1975	.02(.02)	.07(.02)	-.05(.02)	-.04(.02)	.00(.02)	-.01(.02)
1976	.03(.01)	.02(.04)	.01(.02)	-.06(.04)	.01(.02)	.03(.04)
1977	.07(.02)	-.03(.03)	.06(.02)	.07(.03)	.02(.02)	-.01(.03)
1978	.04(.03)	.09(.03)	.05(.03)	-.03(.02)	.03(.02)	-.07(.05)
1979	.03(.02)	-.08(.04)	.08(.03)	.03(.02)	-.03(.03)	-.04(.04)
1980	.08(.02)	.06(.02)	.02(.02)	.03(.03)	-.05(.03)	-.08(.02)
1981	.02(.02)	.00(.02)	.05(.02)	-.01(.02)	.01(.02)	.01(.03)
1982	.06(.02)	.10(.03)	.00(.02)	-.01(.02)	.06(.03)	-.09(.06)
1983	.15(.03)	.00(.02)	-.03(.03)	-.01(.07)	.07(.03)	.05(.04)
1984	.06(.02)	-.04(.02)	-.08(.06)	-.10(.06)	.08(.07)	.14(.05)
	Jul	Aug	Sep	Oct	Nov	Dec
1953	.15(.04)	.06(.02)	.12(.03)	.07(.07)	.08(.03)	.04(.02)
1954	.06(.03)	-.02(.11)	.19(.08)	.04(.01)	.21(.05)	.08(.02)
1955	.08(.04)	.04(.06)	.09(.04)	.09(.02)	.12(.05)	.05(.01)
1956	.02(.06)	.31(.08)	.13(.04)	.14(.03)	.06(.03)	.06(.02)
1957	-.05(.09)	.18(.05)	.05(.03)	.07(.02)	.10(.02)	.11(.02)
1958	.12(.03)	.23(.05)	.12(.02)	.20(.03)	.05(.01)	.06(.02)
1959	.04(.02)	.12(.02)	.17(.06)	.05(.01)	.05(.01)	.04(.01)
1960	.06(.02)	.07(.02)	.06(.02)	.07(.02)	.02(.01)	.06(.02)
1961	.04(.02)	.03(.01)	.08(.02)	.15(.03)	.03(.01)	.04(.01)
1962	.05(.01)	.12(.02)	.10(.02)	.08(.02)	.08(.01)	.09(.02)
1963	.03(.02)	.01(.02)	.09(.02)	.05(.03)	.03(.04)	.07(.02)
1964	.04(.02)	.05(.05)	.10(.03)	.11(.02)	.05(.02)	.04(.02)
1965	.01(.03)	-.02(.02)	.10(.03)	.17(.04)	.13(.03)	.08(.02)
1966	.05(.02)	.15(.03)	.08(.02)	.15(.02)	.06(.01)	.02(.01)
1967	.08(.02)	.06(.04)	-.01(.03)	.09(.03)	.03(.02)	.12(.03)
1968	.03(.04)	.09(.03)	.12(.05)	.11(.02)	.08(.01)	-.06(.04)
1969	.02(.02)	-.02(.02)	.08(.02)	.04(.01)	.07(.01)	.09(.02)
1970	.07(.02)	.08(.02)	.10(.02)	.18(.04)	.12(.03)	.09(.03)
1971	.01(.03)	.14(.04)	-.01(.03)	.00(.03)	.06(.02)	-.02(.04)
1972	.04(.04)	.07(.03)	.12(.08)	.10(.03)	.19(.04)	.14(.03)
1973	-.03(.04)	.01(.05)	.01(.06)	.01(.05)	.01(.02)	.06(.03)
1974	.02(.02)	.04(.03)	.13(.03)	.12(.03)	.03(.03)	.13(.03)
1975	.06(.03)	.03(.05)	.06(.03)	.11(.03)	.08(.03)	.04(.02)
1976	.03(.04)	-.01(.06)	.09(.03)	.15(.03)	.02(.04)	.13(.04)
1977	.05(.07)	-.10(.04)	.10(.03)	.08(.02)	.07(.01)	.02(.03)
1978	-.11(.05)	.04(.04)	.07(.03)	.08(.03)	.07(.02)	.05(.02)
1979	-.01(.03)	.10(.03)	-.02(.04)	.07(.02)	.08(.03)	.06(.06)
1980	-.12(.02)	-.02(.03)	.04(.03)	.05(.02)	.06(.02)	-.01(.02)
1981	-.04(.03)	-.05(.01)	.01(.03)	.07(.02)	.05(.02)	-.04(.01)
1982	.05(.04)	.04(.02)	.01(.06)	.15(.04)	.09(.02)	.08(.02)
1983	-.03(.02)	-.01(.03)	-.10(.03)	.02(.03)	.04(.03)	.04(.03)
1984	.07(.05)	-.12(.05)	.03(.04)	.02(.04)	-.09(.03)	-.01(.03)

Table 7. "Wind cubed" index of rate of addition to the water column, by the wind, of turbulent mixing energy. The standard errors of the mean appear in parentheses to the right of each mean index value. Nominal units are $m^3 sec^{-3}$.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*
1953	130(34)	107(19)	162(35)	473(140)	354(44)	130(47)
1954	75(16)	205(85)	19(4)	186(32)	210(46)	174(41)
1955	132(40)	37(9)	316(101)	93(22)	238(67)	177(50)
1956	58(15)	91(30)	287(46)	355(51)	377(68)	182(25)
1957	101(22)	220(44)	310(23)	375(64)	201(27)	337(42)
1958	184(48)	171(32)	181(25)	260(37)	244(46)	192(21)
1959	116(13)	94(8)	143(14)	154(18)	104(16)	300(47)
1960	84(11)	86(10)	151(15)	207(18)	307(95)	161(19)
1961	71(9)	83(11)	173(24)	178(13)	301(37)	204(26)
1962	156(12)	127(16)	171(14)	220(24)	197(20)	226(19)
1963	113(19)	141(19)	252(17)	176(14)	230(20)	113(13)
1964	188(20)	156(14)	198(27)	295(36)	248(41)	315(117)
1965	100(17)	155(33)	144(16)	238(51)	467(45)	232(20)
1966	247(26)	263(30)	213(25)	312(35)	252(34)	263(24)
1967	147(16)	143(25)	94(13)	102(11)	140(20)	387(80)
1968	47(10)	172(30)	126(15)	120(11)	142(25)	272(25)
1969	97(16)	113(19)	174(18)	206(23)	193(34)	432(68)
1970	121(17)	148(36)	166(38)	232(35)	227(25)	218(20)
1971	92(16)	128(25)	120(15)	266(42)	155(30)	404(162)
1972	102(14)	146(33)	346(70)	214(25)	146(18)	315(51)
1973	247(29)	136(21)	292(26)	333(49)	314(75)	279(52)
1974	121(17)	155(24)	181(20)	308(62)	300(29)	295(39)
1975	135(18)	140(22)	308(24)	251(21)	304(24)	272(33)
1976	76(22)	68(19)	196(27)	326(39)	308(36)	248(53)
1977	134(44)	251(40)	158(21)	265(27)	191(27)	263(30)
1978	150(22)	214(33)	280(44)	316(54)	246(35)	327(91)
1979	202(33)	250(54)	241(23)	282(29)	331(38)	459(122)
1980	179(19)	212(32)	203(21)	194(23)	441(47)	241(18)
1981	205(22)	104(13)	195(19)	212(21)	226(27)	431(73)
1982	134(21)	199(20)	259(19)	201(20)	300(29)	491(97)
1983	319(31)	262(18)	203(21)	420(117)	373(35)	539(61)
1984	118(21)	307(120)	534(117)	288(110)	636(159)	522(116)
	Jul	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1953	332(129)	125(26)	179(34)	217(43)	243(50)	74(16)
1954	207(37)	445(135)	439(73)	64(8)	161(33)	59(13)
1955	179(41)	460(100)	308(76)	322(79)	266(42)	30(13)
1956	324(56)	346(65)	261(29)	237(56)	184(23)	158(35)
1957	484(66)	253(52)	331(45)	261(38)	189(24)	238(22)
1958	214(25)	474(56)	214(26)	228(30)	92(16)	152(26)
1959	138(16)	233(23)	303(76)	164(23)	108(15)	82(13)
1960	260(32)	222(25)	201(19)	198(35)	99(12)	144(24)
1961	290(39)	191(17)	211(20)	199(24)	136(12)	100(12)
1962	265(22)	236(23)	267(32)	199(20)	212(19)	96(15)
1963	220(26)	176(25)	320(31)	376(72)	222(33)	131(19)
1964	250(25)	385(89)	372(58)	242(22)	132(20)	164(21)
1965	263(29)	392(45)	442(52)	319(44)	240(21)	193(20)
1966	317(29)	388(39)	245(18)	243(28)	95(12)	83(10)
1967	222(28)	336(41)	357(59)	369(57)	180(30)	280(45)
1968	442(61)	352(56)	326(62)	243(19)	192(16)	283(42)
1969	237(33)	312(52)	272(29)	154(26)	104(13)	151(23)
1970	248(34)	212(28)	186(22)	251(50)	194(24)	139(22)
1971	190(49)	425(71)	258(66)	302(49)	169(23)	199(57)
1972	423(63)	400(67)	805(139)	220(27)	156(25)	407(157)
1973	369(81)	784(81)	675(74)	348(66)	237(28)	179(37)
1974	299(28)	317(57)	352(45)	295(42)	274(28)	195(31)
1975	284(35)	461(58)	316(31)	235(35)	143(24)	147(23)
1976	264(36)	377(87)	370(33)	328(37)	270(49)	235(43)
1977	529(95)	392(59)	229(37)	189(21)	241(17)	220(34)
1978	434(85)	310(54)	350(82)	226(29)	237(49)	203(28)
1979	290(51)	433(73)	350(51)	274(33)	233(28)	226(50)
1980	458(27)	354(31)	382(35)	271(28)	181(22)	188(30)
1981	420(49)	244(21)	457(60)	166(18)	249(22)	146(13)
1982	438(52)	270(40)	549(82)	454(57)	316(22)	275(30)
1983	379(34)	330(39)	318(43)	277(33)	227(111)	122(32)
1984	334(58)	415(88)	328(46)	242(30)	350(27)	229(22)

Table 8. Daily total (both direct and diffuse) solar radiation absorbed by the ocean, Q_S. The standard error of the mean appears in parentheses to the right of each mean value. Units are watts/m^2. (Values may be converted to units of cal cm^{-2} day^{-1} by multiplying by the factor 2.064.)

	Jan	Feb	Mar	Apr	May	Jun
1953	239(12)	253(9)	262(11)	258(15)	193(9)	182(22)
1954	240(9)	214(10)	227(12)	241(6)	141(7)	158(11)
1955	250(12)	254(12)	236(17)	282(8)	182(17)	125(5)
1956	255(16)	269(16)	257(31)	230(12)	181(14)	121(3)
1957	264(12)	203(11)	243(7)	221(8)	190(10)	153(7)
1958	244(5)	236(8)	243(9)	248(9)	202(8)	148(6)
1959	287(7)	247(8)	241(9)	208(10)	169(12)	144(6)
1960	268(9)	269(4)	283(3)	236(4)	204(4)	167(7)
1961	242(5)	276(5)	228(5)	221(4)	205(6)	140(4)
1962	258(5)	257(4)	260(4)	214(4)	192(6)	143(3)
1963	263(6)	265(5)	240(4)	217(0)	176(4)	139(3)
1964	243(6)	236(4)	242(6)	223(6)	162(8)	161(7)
1965	257(8)	268(7)	236(4)	218(4)	183(4)	165(4)
1966	252(5)	279(5)	246(5)	236(4)	182(5)	148(4)
1967	218(5)	264(8)	244(5)	230(4)	207(6)	138(5)
1968	250(7)	263(5)	265(5)	244(4)	174(6)	149(4)
1969	248(7)	257(6)	238(4)	216(5)	168(7)	140(4)
1970	245(7)	274(7)	280(4)	236(7)	178(5)	140(2)
1971	264(6)	255(6)	261(5)	230(7)	169(8)	130(6)
1972	256(6)	271(7)	237(6)	221(5)	170(6)	145(6)
1973	236(7)	247(9)	237(5)	229(7)	216(7)	151(7)
1974	250(6)	268(7)	257(5)	219(8)	156(4)	131(3)
1975	234(7)	268(6)	240(4)	224(5)	163(4)	131(3)
1976	245(7)	248(13)	234(5)	218(8)	178(6)	130(5)
1977	259(8)	235(4)	244(6)	253(4)	187(5)	154(5)
1978	258(8)	240(7)	265(6)	217(6)	190(6)	153(9)
1979	270(5)	264(7)	246(5)	238(5)	171(5)	142(7)
1980	248(6)	261(5)	244(5)	231(7)	187(4)	156(5)
1981	233(5)	241(5)	249(5)	218(5)	183(6)	142(3)
1982	246(6)	257(5)	246(4)	230(5)	187(5)	139(6)
1983	260(8)	273(4)	236(5)	201(5)	163(4)	149(5)
1984	263(9)	268(7)	260(10)	223(10)	204(29)	142(6)
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1953	170(20)	142(3)	204(12)	227(16)	211(13)	266(15)
1954	149(8)	144(5)	158(5)	192(7)	225(19)	184(11)
1955	123(2)	154(7)	159(2)	217(10)	241(15)	263(26)
1956	134(7)	157(11)	184(9)	198(10)	195(9)	261(31)
1957	143(11)	170(12)	186(8)	211(6)	216(8)	235(6)
1958	154(11)	165(5)	173(7)	218(9)	254(8)	278(13)
1959	154(6)	169(8)	190(8)	218(13)	226(7)	256(6)
1960	163(4)	171(6)	171(4)	185(5)	219(11)	235(7)
1961	126(2)	159(3)	170(2)	210(6)	243(4)	240(5)
1962	133(2)	148(2)	173(5)	193(4)	211(4)	258(6)
1963	145(4)	167(6)	177(4)	204(6)	212(6)	229(9)
1964	138(4)	154(5)	183(5)	191(3)	210(7)	257(6)
1965	135(4)	148(3)	169(3)	197(5)	219(4)	241(5)
1966	151(4)	162(4)	181(3)	191(3)	202(4)	241(5)
1967	137(4)	148(3)	184(5)	195(5)	196(5)	258(6)
1968	145(5)	145(3)	180(5)	201(4)	214(5)	256(7)
1969	137(5)	158(4)	165(3)	205(5)	226(5)	246(6)
1970	134(4)	152(4)	181(4)	180(3)	244(5)	235(7)
1971	127(2)	151(4)	171(7)	193(7)	236(6)	233(10)
1972	138(7)	161(6)	183(8)	209(6)	195(7)	229(9)
1973	142(4)	149(3)	174(5)	205(7)	208(5)	221(6)
1974	127(2)	154(4)	175(4)	218(8)	222(6)	250(8)
1975	134(4)	156(5)	173(4)	212(7)	211(7)	234(6)
1976	147(5)	143(6)	194(6)	206(6)	212(8)	257(8)
1977	134(4)	155(5)	187(6)	204(5)	223(4)	270(8)
1978	126(2)	160(5)	187(6)	205(7)	231(7)	264(6)
1979	138(4)	167(5)	179(5)	217(8)	210(6)	252(12)
1980	139(5)	158(4)	196(5)	208(5)	231(8)	266(9)
1981	139(4)	168(6)	169(2)	235(6)	241(4)	255(4)
1982	150(6)	151(4)	186(6)	215(5)	218(5)	253(6)
1983	156(5)	161(7)	184(12)	198(4)	258(12)	246(10)
1984	157(7)	165(6)	175(16)	185(6)	246(16)	242(9)

Table 9. Radiative heat loss, Q_B. The standard error of the mean appears in parentheses to the right of each mean value. Units are watts/m^2. (Values may be converted to units of cal cm^{-2} day^{-1} by multiplying by the factor 2.064.)

	Jan	Feb	Mar	Apr	May	Jun
1953	23(2)	28(2)	32(3)	41(5)	33(3)	33(10)
1954	26(2)	16(2)	22(3)	43(2)	16(3)	30(5)
1955	30(3)	27(3)	29(5)	60(5)	29(7)	10(2)
1956	33(5)	34(5)	38(13)	41(5)	28(5)	7(1)
1957	33(3)	13(2)	26(2)	29(2)	28(3)	21(2)
1958	24(1)	22(2)	27(2)	39(3)	36(2)	20(2)
1959	43(2)	24(2)	28(2)	29(3)	22(4)	18(2)
1960	32(2)	33(1)	44(1)	37(1)	38(1)	31(3)
1961	26(1)	34(1)	25(1)	34(1)	39(2)	19(1)
1962	31(1)	31(1)	36(1)	30(1)	35(2)	21(1)
1963	33(1)	31(1)	27(1)	34(0)	27(1)	18(1)
1964	27(1)	23(1)	30(1)	34(2)	23(3)	30(3)
1965	33(2)	34(2)	27(1)	27(1)	27(1)	28(1)
1966	30(1)	37(1)	29(1)	38(1)	29(1)	21(1)
1967	20(1)	33(2)	30(1)	34(1)	38(2)	19(2)
1968	33(2)	33(1)	36(1)	44(1)	28(2)	23(2)
1969	29(2)	30(1)	28(1)	29(1)	23(2)	18(1)
1970	29(2)	35(2)	42(1)	37(2)	29(2)	19(1)
1971	34(1)	30(1)	35(1)	34(2)	26(3)	15(2)
1972	32(1)	32(2)	24(1)	31(2)	24(2)	18(2)
1973	22(1)	24(2)	27(1)	36(2)	43(2)	25(3)
1974	30(1)	33(2)	33(1)	34(2)	20(1)	14(1)
1975	23(1)	32(1)	27(1)	32(1)	23(1)	15(1)
1976	27(1)	30(5)	25(1)	31(2)	29(2)	14(2)
1977	30(2)	22(1)	29(1)	43(1)	33(2)	25(2)
1978	31(2)	24(2)	34(1)	31(2)	33(2)	25(4)
1979	33(1)	30(1)	27(1)	36(1)	25(2)	20(3)
1980	30(1)	29(1)	28(1)	34(2)	31(1)	25(2)
1981	24(1)	24(1)	31(1)	31(1)	28(2)	18(1)
1982	29(1)	28(1)	0(1)	35(1)	32(2)	16(2)
1983	28(2)	31(1)	22(1)	20(1)	18(1)	19(2)
1984	29(2)	31(2)	32(3)	29(3)	37(10)	17(2)
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1953	30(9)	9(1)	22(4)	26(5)	20(4)	34(3)
1954	20(3)	11(3)	10(2)	14(2)	23(5)	12(3)
1955	8(0)	14(3)	8(1)	22(3)	31(5)	39(10)
1956	16(3)	18(5)	15(3)	19(4)	15(3)	35(9)
1957	17(5)	19(4)	18(2)	21(2)	22(2)	25(1)
1958	22(4)	20(2)	14(2)	25(3)	35(2)	43(4)
1959	22(2)	19(3)	21(3)	24(5)	25(2)	34(1)
1960	27(1)	23(2)	15(1)	11(1)	23(3)	27(2)
1961	10(0)	17(1)	13(0)	20(2)	31(1)	29(1)
1962	14(0)	11(0)	15(1)	15(1)	20(1)	37(2)
1963	19(1)	19(2)	14(1)	18(2)	21(2)	26(2)
1964	15(1)	15(2)	16(1)	15(1)	20(2)	35(1)
1965	14(1)	13(1)	12(0)	15(1)	22(1)	29(1)
1966	22(1)	18(1)	16(1)	14(1)	17(1)	29(1)
1967	15(1)	13(1)	17(2)	16(2)	15(1)	39(2)
1968	20(3)	11(1)	14(1)	17(1)	22(1)	34(2)
1969	15(2)	17(1)	12(1)	18(1)	26(1)	31(1)
1970	15(2)	13(1)	16(1)	10(1)	32(1)	29(2)
1971	11(1)	13(1)	12(2)	17(3)	28(2)	26(3)
1972	15(2)	19(2)	15(2)	20(2)	15(2)	25(2)
1973	17(1)	12(1)	15(1)	20(2)	18(1)	23(1)
1974	13(1)	14(1)	15(1)	23(2)	23(2)	32(2)
1975	15(1)	14(2)	14(1)	23(2)	20(2)	28(2)
1976	19(2)	11(1)	20(1)	18(1)	19(2)	33(2)
1977	14(1)	16(2)	17(2)	19(1)	23(1)	41(2)
1978	9(0)	17(2)	19(2)	19(2)	25(2)	34(1)
1979	16(2)	19(2)	15(1)	22(2)	19(2)	32(4)
1980	13(1)	15(1)	20(1)	19(1)	27(2)	38(2)
1981	15(1)	19(2)	11(0)	29(2)	30(1)	35(1)
1982	19(2)	13(1)	17(2)	21(1)	20(1)	30(1)
1983	24(2)	17(2)	15(3)	15(1)	33(3)	28(3)
1984	21(2)	22(2)	18(8)	11(1)	29(5)	29(3)

Table 10. Evaporative heat loss, Q_c. The standard error of the mean appears in parentheses to the right of each mean value. Units are watts/m^2. (Values may be converted to units of cal cm^{-2}day^{-1} by multiplying by the factor 2.064.)

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*
1953	3(6)	34(10)	39(8)	62(16)	97(11)	8(9)
1954	-23(5)	15(4)	8(3)	-24(4)	27(5)	33(4)
1955	22(7)	-26(5)	39(16)	14(10)	-14(12)	6(5)
1956	17(6)	-27(13)	-1(25)	39(11)	23(9)	33(6)
1957	-11(3)	43(9)	46(10)	68(13)	59(8)	64(11)
1958	22(4)	65(7)	31(8)	37(6)	49(11)	40(5)
1959	15(3)	15(4)	59(9)	42(7)	21(10)	35(6)
1960	11(2)	18(2)	32(4)	22(3)	15(1)	24(4)
1961	9(2)	22(2)	15(4)	18(2)	34(4)	36(4)
1962	22(2)	33(3)	16(3)	16(4)	26(3)	50(3)
1963	16(3)	24(2)	35(3)	31(0)	46(3)	31(2)
1964	25(3)	25(2)	19(3)	34(7)	28(5)	30(6)
1965	34(6)	46(5)	45(3)	57(5)	109(7)	62(3)
1966	36(4)	63(6)	30(4)	51(6)	44(4)	40(3)
1967	17(2)	33(4)	22(3)	14(2)	15(3)	52(8)
1968	6(1)	36(4)	24(3)	12(2)	26(4)	38(4)
1969	28(4)	19(3)	44(3)	51(5)	57(6)	69(5)
1970	29(4)	31(11)	34(4)	22(6)	22(4)	24(2)
1971	14(2)	11(4)	6(4)	40(6)	39(6)	46(10)
1972	20(3)	48(8)	62(9)	48(4)	62(6)	31(6)
1973	47(12)	28(7)	39(4)	30(6)	28(8)	32(9)
1974	26(3)	26(5)	40(4)	58(9)	70(5)	42(4)
1975	26(5)	21(3)	55(4)	54(6)	70(4)	44(4)
1976	10(2)	48(22)	32(6)	62(9)	64(6)	57(6)
1977	25(4)	43(5)	15(4)	13(5)	21(4)	39(6)
1978	21(3)	38(4)	34(6)	54(6)	23(3)	62(11)
1979	27(4)	35(6)	30(4)	38(6)	45(5)	40(6)
1980	28(6)	24(5)	37(4)	15(3)	57(5)	31(4)
1981	12(5)	19(3)	14(3)	29(5)	42(5)	51(4)
1982	18(2)	21(5)	39(5)	28(3)	46(5)	87(23)
1983	71(5)	97(5)	87(4)	110(10)	124(5)	125(14)
1984	4(10)	31(7)	49(15)	41(15)	-11(15)	32(8)
	Jul	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1953	41(13)	53(4)	29(6)	33(8)	32(7)	8(8)
1954	6(6)	38(10)	17(6)	-8(4)	15(8)	25(12)
1955	46(10)	2(11)	8(5)	-9(8)	9(4)	2(5)
1956	69(11)	35(10)	49(7)	21(4)	69(8)	-9(3)
1957	111(19)	39(11)	54(7)	42(3)	35(4)	18(6)
1958	56(6)	35(3)	31(4)	40(5)	21(4)	27(5)
1959	26(2)	12(3)	30(7)	24(11)	13(1)	2(1)
1960	38(3)	28(3)	28(2)	23(4)	27(5)	20(5)
1961	34(5)	37(2)	28(2)	18(2)	27(2)	14(2)
1962	33(2)	27(2)	26(3)	24(2)	28(2)	15(2)
1963	40(3)	38(4)	43(3)	37(4)	36(4)	24(3)
1964	40(4)	37(4)	31(3)	30(3)	17(3)	27(3)
1965	60(4)	64(5)	36(3)	29(4)	36(2)	33(3)
1966	53(3)	29(2)	32(2)	26(2)	19(2)	13(1)
1967	36(2)	34(4)	22(2)	19(4)	24(3)	26(3)
1968	63(6)	29(3)	34(3)	29(2)	22(2)	33(6)
1969	41(4)	43(4)	31(4)	16(3)	10(1)	15(3)
1970	19(3)	23(3)	21(3)	15(3)	19(2)	15(3)
1971	39(4)	44(6)	31(7)	34(5)	19(3)	31(5)
1972	66(10)	105(10)	70(12)	40(4)	37(5)	42(8)
1973	42(7)	27(6)	29(4)	31(5)	15(5)	15(4)
1974	61(3)	32(3)	25(5)	28(5)	37(4)	33(7)
1975	54(6)	54(6)	23(5)	18(3)	4(2)	16(3)
1976	74(5)	30(17)	50(4)	45(7)	38(6)	34(3)
1977	48(6)	32(4)	19(3)	48(7)	23(2)	18(2)
1978	36(12)	30(9)	32(3)	31(5)	25(6)	24(4)
1979	39(4)	26(3)	37(3)	27(4)	37(7)	20(5)
1980	28(4)	29(4)	28(3)	34(6)	20(4)	15(4)
1981	41(6)	29(3)	27(4)	21(3)	21(3)	19(2)
1982	71(9)	30(6)	34(10)	59(4)	66(5)	68(10)
1983	91(8)	18(15)	46(17)	40(4)	42(7)	15(10)
1984	54(8)	37(5)	54(20)	19(8)	13(17)	26(8)

Table 11. Net atmosphere - ocean heat exchange, Q_N. The standard error of the mean appears in parentheses to the right of each mean value. Units are watts/m^2. (Values may be converted to units of cal cm^{-2} day^{-1} by multiplying by the factor 2.064.)

	Jan	Feb	Mar	Apr	May	Jun
1953	220(13)	193(13)	196(13)	152(24)	51(16)	142(10)
1954	261(11)	187(10)	200(9)	247(9)	101(8)	89(10)
1955	194(13)	273(11)	164(22)	211(16)	192(20)	115(8)
1956	208(12)	286(25)	232(22)	150(15)	137(18)	79(9)
1957	258(11)	143(16)	176(16)	125(17)	103(11)	63(16)
1958	203(7)	146(9)	189(15)	171(10)	110(16)	81(8)
1959	236(7)	215(9)	155(13)	139(13)	125(18)	92(9)
1960	228(8)	220(4)	209(6)	182(5)	153(4)	113(7)
1961	211(5)	221(4)	193(7)	175(4)	133(7)	83(6)
1962	210(5)	195(5)	216(6)	177(6)	135(6)	69(4)
1963	219(7)	213(5)	185(5)	156(0)	100(6)	88(3)
1964	196(6)	192(4)	199(6)	156(10)	111(11)	104(10)
1965	190(8)	187(8)	164(4)	135(7)	35(9)	69(6)
1966	188(7)	179(7)	187(6)	145(9)	108(6)	86(5)
1967	183(5)	202(6)	196(4)	187(4)	157(5)	62(9)
1968	214(5)	196(5)	207(4)	196(4)	118(6)	86(5)
1969	195(6)	209(6)	164(5)	134(7)	82(10)	41(8)
1970	185(8)	212(13)	203(7)	184(10)	130(7)	101(3)
1971	220(5)	219(8)	230(7)	155(9)	99(9)	67(13)
1972	205(5)	188(12)	150(11)	142(7)	77(10)	99(10)
1973	173(16)	203(11)	172(7)	171(11)	153(11)	95(13)
1974	197(6)	211(8)	187(6)	128(13)	63(7)	75(5)
1975	187(8)	217(6)	157(7)	138(9)	62(7)	66(6)
1976	215(6)	166(22)	179(9)	124(14)	78(9)	58(8)
1977	209(9)	174(6)	210(9)	218(9)	142(7)	92(9)
1978	209(8)	185(7)	200(9)	130(10)	139(7)	64(15)
1979	213(8)	204(9)	192(7)	166(10)	101(8)	82(9)
1980	198(9)	217(8)	184(6)	190(8)	99(8)	103(6)
1981	211(8)	202(6)	214(5)	166(9)	114(7)	75(5)
1982	207(5)	220(9)	182(6)	172(5)	111(7)	26(31)
1983	161(8)	139(7)	121(7)	66(14)	8(6)	-8(17)
1984	240(14)	213(11)	180(17)	158(19)	197(24)	101(14)

	Jul	Aug	Sep	Oct	Nov	Dec
1953	91(26)	74(6)	151(11)	171(16)	157(14)	227(19)
1954	135(14)	93(15)	138(9)	201(8)	183(19)	143(16)
1955	58(14)	152(18)	140(9)	222(15)	215(13)	226(17)
1956	34(15)	97(15)	109(8)	166(9)	98(13)	245(22)
1957	12(23)	110(18)	108(12)	144(6)	158(7)	200(9)
1958	69(12)	112(6)	127(8)	149(9)	198(8)	204(11)
1959	104(5)	139(6)	140(11)	174(18)	189(5)	224(5)
1960	95(5)	120(6)	129(4)	152(7)	172(12)	193(7)
1961	80(7)	103(4)	130(3)	173(5)	189(4)	203(5)
1962	89(3)	111(3)	140(6)	157(4)	167(4)	211(5)
1963	83(5)	106(7)	120(6)	155(7)	155(7)	183(8)
1964	78(6)	102(7)	138(5)	145(4)	173(6)	198(5)
1965	58(7)	66(7)	121(5)	154(6)	161(4)	180(5)
1966	70(5)	114(4)	131(3)	151(3)	166(4)	200(4)
1967	85(4)	97(5)	144(5)	169(7)	156(5)	196(6)
1968	55(9)	108(4)	135(5)	157(5)	174(4)	192(7)
1969	75(6)	93(6)	121(6)	170(5)	192(4)	203(5)
1970	102(4)	117(5)	146(5)	165(5)	195(5)	198(7)
1971	71(6)	92(10)	128(11)	142(8)	194(6)	176(9)
1972	51(15)	23(13)	98(17)	145(7)	147(8)	171(10)
1973	77(11)	120(10)	144(7)	157(9)	187(9)	191(7)
1974	46(5)	106(6)	141(7)	175(9)	166(8)	183(12)
1975	63(8)	79(10)	144(8)	178(5)	197(5)	195(6)
1976	52(8)	116(25)	122(8)	148(9)	162(9)	195(7)
1977	72(9)	111(6)	156(7)	131(10)	181(4)	222(7)
1978	89(16)	118(14)	138(6)	158(8)	191(10)	208(7)
1979	86(7)	133(6)	131(6)	171(7)	158(10)	207(10)
1980	105(8)	117(7)	154(6)	156(10)	192(9)	220(9)
1981	83(8)	119(6)	139(5)	191(6)	196(5)	207(4)
1982	59(12)	114(8)	144(14)	132(6)	129(7)	155(13)
1983	34(10)	139(19)	136(25)	145(7)	184(15)	216(15)
1984	78(12)	108(10)	121(36)	166(14)	228(25)	190(11)

uncommon in the figure with the notable exception of the early 1970s and again in the early 1980s. The main point is that features in Fig. 4L seem unrelated to any major features apparent in the other series plotted in Fig. 4. Thus, the major effect of uneven distribution of reports appears to be in increasing sampling variance rather than in introducing long-term nonhomogeneity in the various time series.

Discussion

Since the 12-month running mean filter used to highlight the long-term variations in Fig. 4 incorporates no data more than 6 months previous or following, the indicated multiyear features are certainly real, and in no way represent artifacts of filtering and smoothing procedures. Moreover, the interyear variations of annual mean values tend to be of similar magnitude to the cyclic seasonal components (Figs. 2 and 3), making the separation of these scales in analysis of effects (e.g., on the biota) a difficult problem. For example, the impact of long-term variability will generally depend on phase relationships with the seasonal variation. Additional complications involve the adaptations of the biota, not only the long-term evolutionary adaptations of life cycle processes to regular cyclic effects, but also lagged responses of community composition, etc., to events of the recent past (see Mendelsohn and Mendo, this vol.).

This area of the world's ocean may be uniquely troublesome in these respects. Because the Pacific Ocean is so large, it is much less subject to continental effects which amplify seasonalities due to the low heat storage capacities of continents relative to oceans. The apparent consequence is much less forcing of Pacific Ocean processes to follow a regular seasonal cycle than may be the case, for example, in the Atlantic; the result is the dominance of interyear variation in the Pacific (Picaut 1985). The location so near to the eastern terminus of the equatorial wave guide results in a focusing of variability initiated in various portions of the great Pacific ocean-atmosphere coupled system to particularly impact the ocean habitat off Peru. Indeed, this may constitute part of the explanation for the enormous biomasses of pelagic fishes that have inhabited the region; i.e., because of the intense irregular environmental variability, a single, rather unspecialized fish species with very rapid population responses may be able to dominate the system relatively free from predation and competition from more specialized, less responsive species that would be more subject to the inefficiencies of multiple food-chain steps.

We have noted that the interyear variations tend to involve groups of years. In fact single features, e.g., the 1982-1983 El Niño, the 1954-1955 cold period, etc., so dominate the series that the entire series length becomes a dominant scale of variability. The result is that any sort of assumption of stationarity must be somewhat unrealistic; the real degrees of freedom useful for empirical analysis nearly vanish with respect to such features. It is also apparent from even casual inspection of Fig. 4 that the index series presented in this paper are all highly interrelated in terms of major interyear features, further exacerbating the problems of empirically sorting the various effects. Any available mechanistic constraints, provided by established physical or biological principles, that can be imposed on empirical analysis, would of course be very helpful in this situation.

Variable vs. Constant Transfer Coefficient Formulations

Some differences in the results of variable and constant transfer coefficient formulations in the wind stress estimates (Equation 1) and in the estimates of certain of the heat exchange components (Equations 4, 5 and 6) have been noted in the discussions of both seasonal and interyear variability. The differences have mainly been in magnitude of the particular index, with temporal aspects of the variability appearing to be relatively unaffected. An exception was the conductive component of heat exchange, Q_C, where the effect of stability in the atmospheric boundary layer introduced major discrepancies between the alternate formulations (Fig. 3E). Fortunately, Q_C is by far the smallest heat exchange component. Some summary information concerning gross effects of the differences in the various series with respect to time series properties is indicated in Fig. 5.

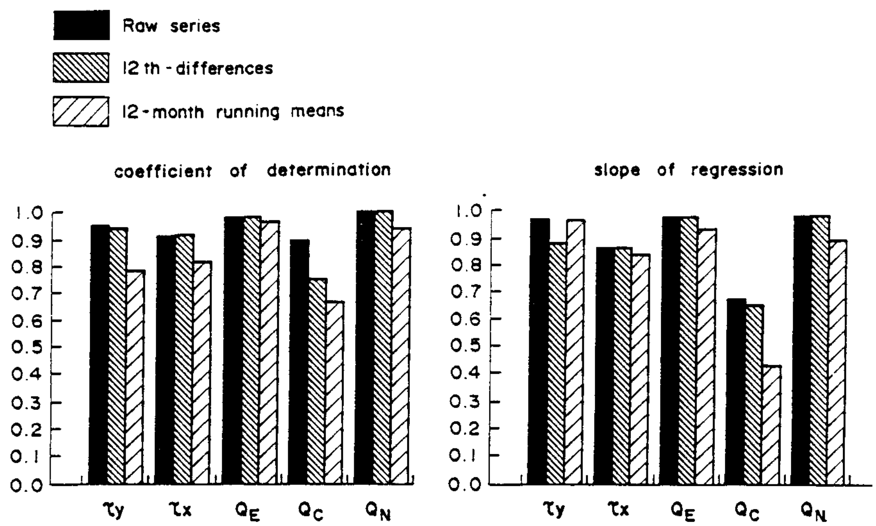

Fig. 5. Graphs of r^2 (= coefficient of determination, i.e., proportion of variation in one series 'explained' by other series) and slope of the regression of the variable transfer coefficient formulation versus the constant transfer coefficient formulation of alongshore stress (τ_x), onshore stress (τ_y), evaporative heat loss (Q_E), conductive heat loss (Q_C) and net atmosphere-ocean heat exchange (Q_N).

In the case of alongshore component of wind stress, the raw monthly series computed according to the two types of drag coefficient formulation are well correlated, each accounting for more than 95% of the variance in the other. When 12th-differencing was employed to remove the cyclic seasonal variations, the correlation dropped only slightly; this lower than expected drop in r^2 must be due to a strong seasonality in the differences resulting from the two formulations. Note that both the raw and 12th-differenced series pairs were much more highly correlated than the pair of 12-month running mean filtered series (which can be viewed in terms of directly proportional offshore Ekman transport in Fig. 4G). The slope of the regression of the variable coefficient alongshore stress series on the constant coefficient series is nearly one to one in the raw series; it drops to below 0.9 in the 12-differenced series, but is above 0.95 in the filtered series.

Slightly lower degrees of relationship are seen for the onshore component which tends to be much the smaller of the two stress components. The respective formulations of evaporative heat loss (Q_E) were very highly correlated in raw and 12th-differenced series. The degree of relationship fell only slightly after the 12-month running mean was applied. In the case of the conductive heat loss term (Q_C), the two formulations gave substantially greater differences, particularly after 12th-differencing or filtering. In the case of net heat exchange (Q_N) the differences between the results of the two formulations appear not to be appreciable. Note that in all cases the raw and 12-differenced series were more highly correlated between the constant and variable coefficient formulations than were the corresponding 12-month running mean filtered versions of the respective series; thus the degree of relationship is even higher in the case of the unsmoothed series, even after the seasonality is removed, than can be seen in the comparative examples of filtered series in Fig. 4.

In view of the time series similarities, the constant transfer coefficient versions of the respective index series are the only ones presented herein in tabular form (Tables 5, 6, 10 and 11). In view of the larger relative effect of the uncertainties as to proper formulation of the transfer coefficient for conductive heat loss, and because its very small magnitude makes it relatively unimportant in any case, no tabular series of Q_C is included. Of course, it would be possible to assemble the constant coefficient version of the Q_C series from the values in Tables 8 to 11.

Offshore Ekman Velocity of the Mixed Layer

In discussing the inference of Parrish et al. (1983) that the offshore Ekman transport should ideally be divided by the effective mixed layer depth, to yield the net rate of offshore transport of drifting larvae which are passively mixed through the layer, Bakun (1985) stressed the importance of the qualification "ideally". Ekman transport is estimated from relatively abundant surface wind reports, which reflect the fairly large spatial scales of atmospheric variation. Mixed layer depth may vary on much shorter oceanic length scales and must be determined from generally much less abundant subsurface observations. In cases where the estimate of effective mixed layer depth may be very imprecise, the derived estimate of offshore Ekman velocity of the mixed layer could constitute a less reliable indicator of variability in this process than the Ekman transport alone.

On long time scales, mixed layer depth and wind stress observations are likely to be substantially correlated. However, within any given month it is probably not too bad an assumption to regard observations used to estimate these quantities (surface wind and subsurface temperature structure) as largely independent samples of the respective monthly distributions, particularly since there will normally be many more surface than subsurface reports. In this case, combining the standard errors according to the rules for a quotient of independently observed quantities (e.g., Beers 1953) should provide a reasonable gauge of precision. Thus the ratio of the standard error to the monthly mean derived net offshore Ekman velocity of the mixed layer might be reasonably estimated as being equivalent to the square root of the sum of the squares of the respective ratios of the standard errors to the monthly mean values of the Ekman transport and mixed layer depth components of the calculation.

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